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BIM Deployment: A Process to Adopt and Implement a Disruptive Technology

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BIM Deployment: A Process to Adopt and Implement a Disruptive Technology

by

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Dedication

To my niece, Dorothy: may this document inspire you to complete your education (do not take as long as your uncle to fulfill).

Acknowledgements

I would like to recognize several people who made this research possible. In particular, I wish to thank my paternal grandmother for stressing the importance of education. I would like to bestow additional appreciation to my mother and father for their unconditional love and continued support; my sister for the determination and strength to complete objectives that may not appear fruitful during the initial phases; and my life-long best friend, Troy H. Long. Many special thanks extended to my mentors: Isaac Green, Garvin Moeller, Joe LaFoy, Jr., and Donald Libby. I appreciate their encouragement to undertake this Master's degree and their continued support and assistance throughout this endeavor. Finally, I extend many thanks to my professors, instructors and classmates at the University of Texas at Austin, and colleagues at J. M. Waller Associates and our numerous teaming partners for contributing to my education in ways far deeper than imagined.

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Abstract

BIM Deployment: A Process to Adopt and Implement a Disruptive Technology

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This thesis determines a process to adopt and implement the disruptive practice and technology of Building Information Modeling (BIM) within the architectural-engineering-construction (AEC) community. Specific areas to address include:

1. Define process, adoption and integration as related to BIM implementation
2. Describe why BIM is a disruptive technology today
3. Identify reactive and proactive BIM outcomes
4. Evaluate and select process options for a specific BIM project
5. Describe the roles and responsibilities of participants, or stakeholders, in the BIM process
6. Identify consistent factors that influence BIM return on investment (ROI) at the project and company levels

7. Communicate the BIM process to management, colleagues and project stakeholders
8. Outline a process for BIM adoption and implementation at the project and company levels

The research methodology includes literature reviews and case studies. This research extends key teachings of the University of Texas at Austin Executive Engineering Management curriculum and gives the reader insight into the adoption and implementation of disruptive technologies.

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Chapter 1: Introduction

Technological change remains critically important to firms for several reasons. First, technology has the potential to obsolete assets, labor, and intellectual capital of incumbents in the market. For example, electronic commerce has obsoleted many of the old business processes in the banking industry. Second, technology can create entirely new markets, with new products, new customers, and exploding demand. For example, MP3 technology facilitated the iPod revolution, with massive demand for products, services, and accessories. Third, technological evolution enables firms to target new segments within a market with improved products. For example, improvements in LCD monitors enabled firms to target the segment of consumers with mobile computing needs. Fourth, and most importantly, businesses often misinterpret the potential impact of the new technology, and this error causes the demise of those businesses or the industry the firms comprise. For example, microcomputers caused the extinction of minicomputers.

This research began by asking the questions: *What barriers and/or opportunities does Building Information Modeling (BIM) present within the architectural-engineering-construction industry, and how does one adopt and implement such a disruptive technology?* Since many approaches may improve adoption and implementation, a specific context necessitated a narrower scope of research. The context centers on facets of my current employment. As a result, the main point of this research concentrates on the adoption and implementation of BIM, a disruptive technology.

This thesis identifies what management practices, processes, skill sets, and workflows best enable engineering managers and other highly technical management professionals in the profession to the adopt and implement BIM. Key premises of this thesis center on the highly fragmented nature of the architectural-engineering-construction (AEC) industry, continued reliance on paper-based business practices, a lack of standardization and inconsistent technology adoption among stakeholders. This thesis identifies the missing ladder rungs by investigating related research works, examining the suppositions made in current business literature, and conducting primary research into the implementation of BIM and other disruptive technologies into the AEC industry.

This thesis determines a process to adopt and implement the disruptive practice and technology of BIM within the AEC industry. The research culminates in the development of a BIM deployment plan. Specific examples of BIM adoption and implementation plans will guide the reader in the application of the methodology for other disruptive technologies. Key areas to address include:

1. Describe why BIM presents a disruptive practice today
2. Define process, adoption and integration as related to BIM implementation
3. Identify reactive and proactive BIM outcomes
4. Evaluate and select process options for a specific BIM project
5. Describe the roles and responsibilities of participants (stakeholders) in the BIM process
6. Identify consistent factors that influence BIM return on investment (ROI) at the project and company levels.
7. Communicate the BIM process to management, colleagues and project stakeholders
8. Outline a process for BIM adoption and implementation at the project and company levels

Chapter 2, Literature Review, discusses selected publications related to BIM adoption and implementation. Research incorporates private sector data gathered from numerous publications and sources. Finally, government research data includes data from the General Services Administration (GSA), National Institute of Building Sciences (NIBS), and the US Army Corps of Engineers (USACE).

Chapter 3, Study Methodology, details the gathering of additional information to meet the thesis objectives. The chapter describes how to select the study target and how to conduct the primary research. Although much of the base data derives from government sources, numerous sources assists in the development of the BIM adoption plan mentioned previously.

Chapter 4, Results, provides a narrative on the key findings of the research conducted. Trends identify and summarize key data in preparation of the final chapter. Using the data gathered from all sources, Chapter 5, the final chapter, culminates with the presentation of the developed adoption and implementation plan for BIM. The chapter includes the recommended plans. This section also addresses the key thesis questions presented on the previous page.

The product of this research includes recommendations for all stakeholder groups engaged in leveraging BIM for the successful integration of computer models into project coordination, simulation and optimization within the AEC industry. Additional related topics of inquiry that fall outside the scope of this research are also included for future investigation. A particularly fascinating aspect of this research centers on my personal "front row seat" as the company I work adopts and implements BIM into workflows and toolbox. This "front row seat" provides the opportunity to witness a research project actually come to life and as a result, part of the research acts as a journal.

Chapter 2: Literature Review

This literature review presents a conceptual framework that creates questions to guide the empirical research. The methodology includes an examination of a number of press publications and academic journals. Organized under central themes, this research involves the importance and differentiation of BIM, processes and workflows, current trends, available technologies, and the future of BIM utilization. By investigating research against the objectives of this thesis, specific areas determine which factors may predict successful adoption, integration and deployment.

BIM presents an emerging tool for design teams, potentially increases efficiency and improves communication among project stakeholders. As a result, one must clearly define BIM. A common misconception, even among design professionals, holds building information modeling only refers to a type of software or physical geometry without processes or workflows. While BIM requires the use of software to perform minimal modeling and information requirements, the software represents a single component. To capitalize on available technologies, stakeholder processes and workflows must fundamentally change. For purposes of this research, BIM includes the integration of technology and the processes and workflows to create virtual models.

The findings indicate several significant conclusions. Research suggests reduction of inflated project overhead, administration, and services costs should the industry adopt BIM in concurrence with actual design, review, permitting and construction processes. Clients could use BIM data to quantify building impacts on energy and resources over time. Because of the high capacity for software to exchange information with third-party analysis tools, sustainable innovation easily integrates within a BIM workflow. Financial barriers, such as software and staff training costs associated with BIM technology, present one specific impediment to overcome. Early in the design process, BIM requires loading projects with more information, which encourages direct collaboration between stakeholders and greater transparency. A fully leveraged BIM workflow may not be feasible for small-scale firms due to the relatively steep learning curve and higher software costs. A hybrid approach, contingent on construction practices and BIM software evolution in the near future, presents a potential solution. BIM centralizes project information, which makes the information accessible and long lasting. This centralization serves as a communication and learning tool across multiple disciplines and between participants.

This chapter discusses the definition of BIM; how the BIM delivery system differs from a traditional computer-aided design (CAD) system; and the benefits from the use of BIM.

IMPORTANCE AND DIFFERENTIATION OF BIM

Throughout history, the design and construction of buildings relies on drawings to represent the work to perform. These drawings represent contracts or legal documents and assist facility management after construction. Strategic limitations exist for drawings: drawings require multiple views to depict a 3-D object in adequate detail for construction, which causes redundancy and exposure to errors; and drawings store lines, arcs and text annotations, interpretable only by some people. Therefore, computers cannot interpret drawings.

BIM remains a huge buzzword in the AEC community. This acronym appears in numerous industry magazines. Multiple conferences held annually feature BIM as the main topic. Software developers headline products as BIM tools.

The Definition of BIM

Numerous definitions exist for BIM. The National Institute of Building Sciences (NIBS) states, “BIM stands for new concepts and practices so greatly improved by innovative information technologies and business structures that dramatically reduce multiple forms of waste and inefficiency in the building industry.”[1] The Associated General Contractors (AGC) possesses a variety of working definitions. These definitions describe BIM as, "an object-oriented building development tool that utilizes 5-D modeling concepts, information technology and software interoperability to design, construct and operate a building project, as well as communicate details."[2]

BIM seems closely related to Integrated Project Delivery (IPD), with the primary motive to bring teams together early in the project. Full implementation of BIM requires teams to collaborate from the inception stage and formulate model sharing, ownership and contract documents. In an environment where organizational collaboration proves crucial during the duration of a project, the construction industry demands a tremendous level of coordination.[3] BIM technologies can lead to major productivity improvements by integrating assets of the construction project network.[4]

A building information model represents physical and functional characteristics of the facility in a digital format. This model provides a shared resource of information about a facility for the owner/operator to use and maintain throughout the life of the facility.[5] However, NIBS notes the acronym BIM contains several uses. BIM refers to a product, an activity, or a system. Figure 2.1 illustrates these three uses.

[1] NIBS 2007, 1
[2] AGC website
[3] Alshawi and Faraj 2002, 33
[4] Taylor and Bernstein 2008
[5] NIBS 2007, 21

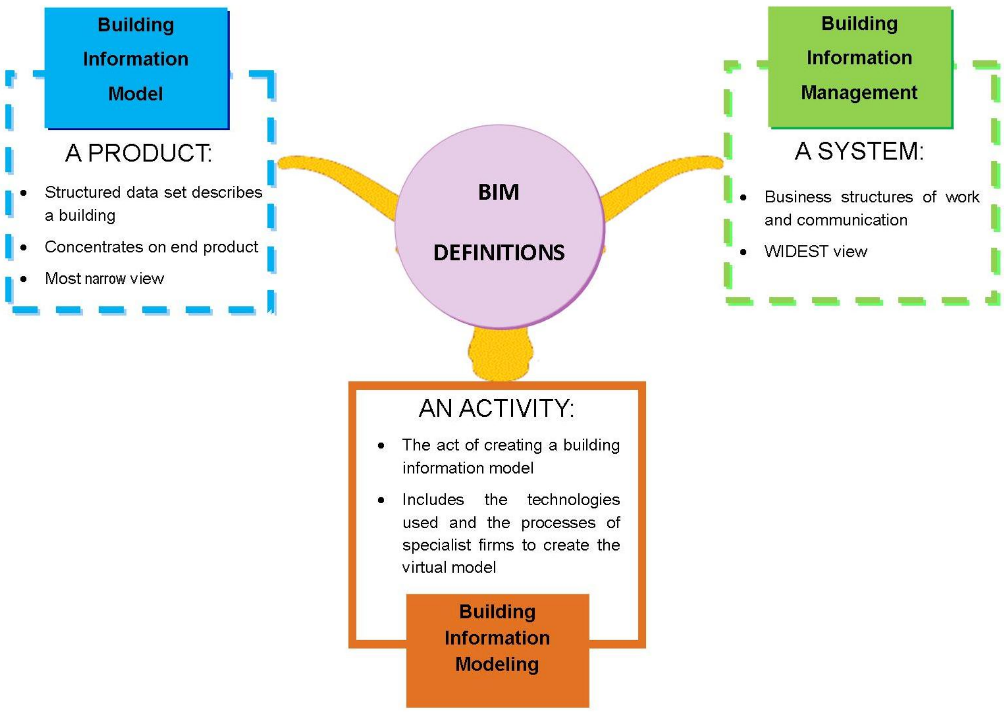

Figure 2.1: Different definitions of BIM

The process of generating and managing data during the life cycle of a facility generally defines BIM.[6] Typically, BIM uses 3-D, real-time, dynamic building modeling software to increase productivity in design and construction.[7] The process produces the BIM, which encompasses building geometry, spatial relationships, geographic information, and quantities and properties of building components.

BIM represents the latest technology to offer significant improvement in the speed, cost, and quality of facility planning, design and construction, and operations and maintenance. One eloquent description states BIM as *an intelligent simulation of design intent*. In practical terms, the potential of BIM stems from its value as an interchange mechanism between the tools used to perform the various functions of the AEC industry

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[6] Lee, G., Sacks, R., and Eastman, C. M. (2006), 758-776
[7] Holness, Gordon V.R. (2008), 28-40

and the ability of computational tools to manipulate the model directly, with or without human intervention. In a typical BIM-enabled process, the data model serves as the principal means for communication between activities and professionals.

BIM most accurately stands for Building Information Modeling. The acronym also defines a Building Information Model. However, this use seems inaccurate since models only represent one of the many products of BIM. To compare CAD technology to BIM technology, BIM relates to CAD as CAD correlates to hand drafting. BIM represents a significant technology leap in capturing design information about a building or structure.

Utilization extends beyond buildings. Civil work projects successfully employ BIM for locks and dams. The capability exists for BIM to model any type of structure. Perhaps in the future, industry will rename BIM as Structure Information Modeling, Facility Information Modeling or Design Information Modeling.

Some people call the building model "a BIM," which references software that generates a BIM. For others, the process of advancing to machine-readable models proves more important than the representation of the models because machine readability offers opportunities for further integration and automation. A building model serves as the basis for BIM and infers BIM as a process. This definition proves consistent with the description outlined by GSA.[8] The process proves revolutionary because BIM provides the opportunity to migrate from practices centered on human artistry to a more augmented and modern machine artisanship.

In this study, BIM refers to Building Information Modeling. This definition emphasizes both technologies and new ways to enable the creation of a virtual building

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[8] www.gsa.gov/bim

information model. According to Taylor and Bernstein BIM means, “a new industry term referring to parametric 3-D CAD technologies and processes.” However, in addition to 3-D, BIM also includes 4-D (time) and 5-D (time-based costs).[9]

Origins of BIM

Charles M. Eastman at Georgia Tech coined the term BIM.[10] This view theorizes the term BIM, "Building Information Model," matches the term "Building Product Model," which Eastman uses extensively in his book[11] and papers since the late 1970s. “Product model” means “data model” or “information model” in the engineering field.

Architect and Autodesk building industry strategist Phil Bernstein, FAIA, first used the actual term BIM "building information modeling." Jerry Laiserin helped popularize and standardize BIM[12] as a common name for the digital representation of the building process offered primarily by Graphisoft, Bentley Systems, and Autodesk to facilitate the exchange and interoperability of information in a digital format. According to Laiserin[13] and others,[14] the first implementation of BIM occurred with the Virtual Building concept in the 1987 debut of Graphisoft ArchiCAD.

In 2003, the GSA, through its Public Buildings Service (PBS) Office of Chief Architect (OCA), established the National 3D-4D-BIM Program. OCA has led over 30 projects in its capital program, and assesses and supports 3-D, 4-D, and BIM applications in over 35 ongoing projects across the nation. The power of visualization, coordination, simulation, and optimization from 3-D, 4-D, and BIM computer technologies allow GSA

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[9] Kraus et al. 2007, 1
[10] www.aecbytes.com/viewpoint/2004/issue_10.html
[11] Eastman, C.M., Building Product Models
[12] Laiserin's explanation of why 'BIM' should be an industry standard-term
[13] Graphisoft on BIM
[14] Building Information Modeling Two Years Later –Huge Potential, Some Success and Several Limitations

to better effectively meet customer, design, construction, and program requirements. GSA remains committed to a strategic and incremental adoption of 3-D, 4-D, and BIM technologies.

What Differentiates BIM?

Currently, technology supports the progression from 2-D to 3-D and BIM. While 3-D models make valuable contributions to communications, not all 3-D models qualify as BIM models since a 3D-geometric represents only part of the BIM concept. The inclusion of information (the “I” in BIM) to generate feedback proves critical to successful integration of computer models into project coordination, optimization, and simulation. As a shared knowledge resource, BIM serves as a reliable basis for decision-making and reduce the need for repetitive gathering or formatting information. GSA currently explores the use of BIM technology throughout a project lifecycle in the following areas: spatial program validation, 4-D phasing, laser scanning, energy and sustainability, circulation and security validation, and building elements.

For all major projects receiving design funding in Fiscal Year 2007 and beyond, GSA requires spatial program BIM as the minimum requirement of submission for Final Concept approvals by the PBS Commissioner and the Chief Architect. At the same time, GSA encourages all projects deploy mature 3-D, 4-D, and BIM technologies - spatial program validation and beyond - at strategic project phases in support of specific project challenges. The following points highlight the GSA National 3D-4D-BIM Program:

- Establish policy to phase in 3-D, 4-D, and BIM adoption for all major projects
- Assess industry readiness and technology maturity
- Create GSA-specific incentives for 3D-4D-BIM
- Develop solicitation and contractual language for 3D-4D-BIM service

- Partner with BIM vendors, professional associations, open standard organizations, and academic/research institutions
- Construct GSA BIM Toolkit
- Publish BIM Guide Series
- Establish knowledge portal community
- Build a community of BIM Champions

As a companion to Product Lifecycle Management, BIM extends beyond geometry, addresses issues such as cost management and project management, and provides a way to work concurrently on most aspects of building lifecycle processes. BIM reaches far beyond switching to new software and requires changes to the definition of traditional architectural phases and more data sharing than most architects and engineers currently utilize. By modeling representations of the actual parts and pieces used to construct a building, BIM achieves improvements. This process represents a substantial shift from the traditional CAD method of drawing with vector file-based lines that combine to represent objects.

Interoperability requirements of construction documents include the drawings, procurement details, environmental conditions, submittal processes and other specifications for building quality. Proponents anticipate BIM utilization bridges the information loss associated with handing a project from design team to construction team to building owner/operator. The BIM model allows each group to modify and reference all information acquired during contribution periods. For example, a building owner may find evidence of a leak in the building. Rather than explore the physical building, the owner may turn to the BIM and see a water valve located in the suspect location. The owner may possess a model with the specific valve size, manufacturer, part number, and other information researched in the past, pending adequate computing power. Leite initially addresses such problems through development of a vulnerability representation for facility contents and threats that support the identification of vulnerabilities in building emergencies.[15]

There have been attempts at creating a BIM for existing facilities. These attempts generally reference key metrics, such as the Facility Condition Index (FCI). Validity of these models needs monitoring over time because endeavors to model a building constructed in 1927, for example, require numerous assumptions about design standards, building codes, construction methods and materials. These assumptions prove far more complex than building a BIM at the time of initial design.

BIM represents a design as objects – vague and undefined, generic or product-specific, solid shapes or void-space oriented (like the shape of a room) - that carry object geometry, relations and attributes. The geometry may consist of 2-D or 3-D data, and objects which entail abstract and conceptual or construction details. Together these data objects define a building model. If an object changes or moves, the data object needs action. BIM design tools allow for extracting different views from a building model for drawing production and other uses. These different views eliminate redundancy of objects, and objects remain consistent with regard to size, location and specification. Drawing consistency eradicates many errors.

Modern BIM design tools go further. These tools define parametric objects with defined parameters and relationships to other objects. These relationships prove important because as a related object changes, the parametric object also changes. Parametric objects automatically rebuild according to the rules embedded within the objects. The rules range from simple to complex. As an example, a simple rule requires

[15]Leite, F.; Akinci, B.; Garrett, J.; Akin, O. (2009)

a wall must completely contain a window and allow different placements within the wall. A sample complex rule defines size ranges and details, such as the physical connection between a steel beam and column.

Processes and Workflows

In terms of project workflow, successful BIM implementation necessitates a front-loaded design process, where most of the modeling time is during schematic design and design development phases. During construction documents and construction administration (site visits, reports, and documentation), the workload stays relatively low and occasionally levels off. The benefit of this workloads allow front-loaded projects to reveal potential design problems early in the process, and the necessary coordination among the design team can occur sooner rather than later to resolve any issues. This workflow contrasts with traditional design workflows using CAD tools, where the opposite is true, and most of the drawing time occurs during design development and construction documents. The problem with traditional workflow stems from conflict resolution and design changes tend to happen later in the project timeline, which are more costly than making the same changes early in the timeline. Building information modeling covers geometry, spatial relationships, light analysis, geographic information, quantities and properties of building components (for example, manufacturer details). BIM demonstrates the entire building life cycle, including the processes of construction and facility operation. BIM easily extracts quantities and shared properties of materials, and allows for the isolation and definition of scopes of work. Systems, assemblies and sequences display in a relative scale with the entire facility or group of facilities.

Figure 2.2 illustrates the time and effort relationship between BIM and CAD workflows across project phases.

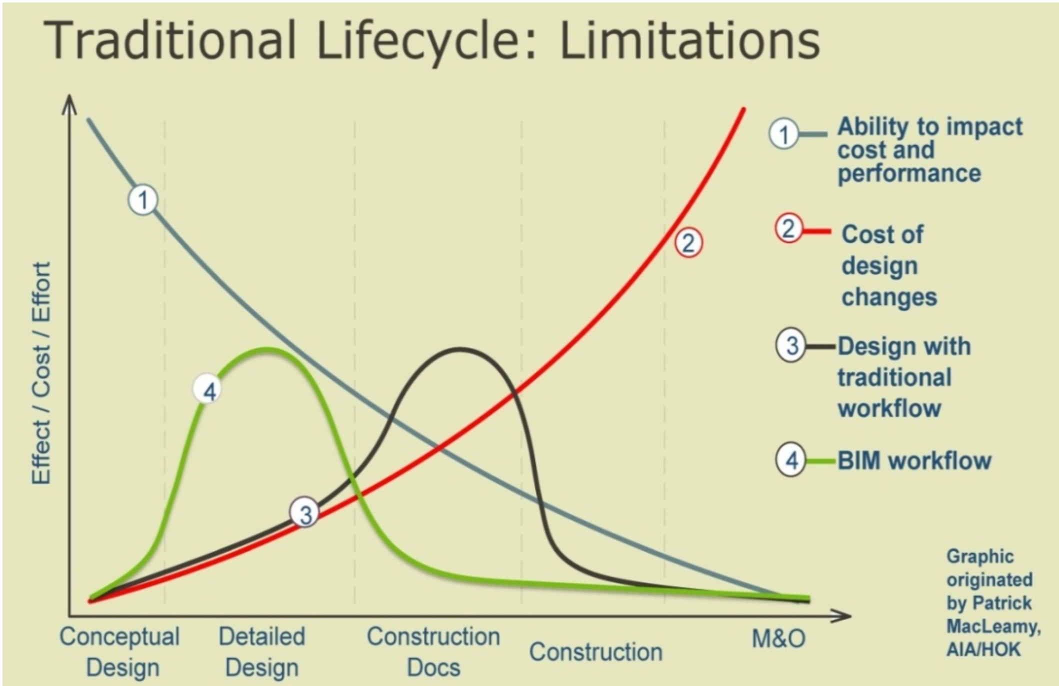

Figure 2.2: Traditional versus BIM/IDP workflows relative to design effort and cost of change over a project timeline.[16]

A major challenge with the emergence of BIM and the increasing project data flows between stakeholders ensures interoperability between technologies and software applications. Although most BIM authoring tools fit the criteria listed at the beginning of this chapter, each tool organizes and understands parameters and object data differently. Eastman, et al. (2008), describes four ways data exchanges occur between applications, direct links between proprietary BIM tools, proprietary file exchange formats, public open-standard exchange formats, and web-based HTML extension schemas.[17]

Direct links between proprietary BIM developers (commercial companies) do not require any modification of the native file format. An example of this includes

[16] Building Information Modeling: A Strategic Implementation Guide for Architects, Engineers, Constructors, and Real Estate Asset Managers, 104.
[17] Eastman, Charles M., et al, BIM Handbook, 66-68.

Autodesk's RVT format for its BIM tool suite. In this case, a single native file type is exchangeable across a single software platform. Proprietary exchange formats, on the other hand, allow information to be transferred between different types of software programs developed by a single company, such as Autodesk's Direct eXchange Format (DXF), which communicates CAD data between current and legacy version. An attempt to bridge BIM model information across AEC industry groups has resulted in the development of a public open-standard exchange format known as the Industry Foundation Class (IFC), supported by the buildingSMART International Alliance for Interoperability (IAI), a non-profit industry led international organization.[18] The IFC represents the most likely option for increasing interoperability between AEC industry groups although at present, barriers exist to adoption and use. Finally, eXtensible Markup Language (XML) exchange formats exist. These formats utilize the HTML language used over the Web as a basis. XML proves beneficial because the format can support small amounts of specific data between software applications. For example, gbXML, which refers to 'green building' XML-format, includes data about heating and cooling information typically used in thermal analysis programs. No single exchange format solution will solve all BIM-related interoperability challenges, and the success of BIM implementation depends on continued support and development of these various exchange strategies.

Earlier collaboration among the design team represents a major opportunity through implementing BIM, which supports the goals of IPD. The American Institute of Architects (AIA) defines IPD as the following: "IPD leverages early contributions of knowledge and expertise through utilization of new technologies, allowing all team

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[18] Eastman, Charles M., et al, BIM Handbook, 72.

members to better realize their highest potentials while expanding the value they provide throughout the project lifecycle."[19] Collaborative, integrated and productive teams composed of key participants comprise the core of an integrated project. Building upon early contributions of individual expertise, several principles guide these teams. These principles include trust, transparent processes, effective collaboration, open information sharing, team success tied to project success, shared risk and reward, value-based decision making, and utilization of technological capabilities and support. The outcome results in the opportunity to design, build, and operate as efficiently as possible.[20]

The AIA further explains various aspects of IPD to include team collaboration and communication; roles, responsibilities, and service scope; measuring project goals; and risk assessment and contracts. AIA envisions IPD as a specific type of project delivery method, which intends to leverage the capabilities of BIM tools. One could argue IPD responds to emerging BIM technologies coupled with the blatant inefficiencies of traditional project workflows and design tools. Interestingly, the AIA defines BIM as merely a tool and IPD as the process workflow, which seems to contradict several leading publications that define BIM as the successful combination of tools and process.[21] This research recognizes different perspectives exist as ideas solidify about BIM and IDP in the building industry.

Perhaps one of the most notable and documented benefits of BIM concerns the cost savings associated with eliminating inaccuracies, redundancies, and waste generated from conventional building practices. According to a 2002 study conducted by The National Institute of Standards and Technology (NIST), inefficiencies in the building

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[19] AIA website
[20] AIA and AIA California Council, Integrated Project Delivery, 2007, 2.
[21] Smith, Tardif 2009 & Eastman, et al. 2008

industry accounted for an average increase in construction costs by $6.35 per square foot for new building design, construction, operations and maintenance.[22] These figures link to inefficient management practices, the recollection/reentry of data, and the stalling of resources (human and material) throughout the project phases. Early adopters of BIM in the construction industry have reported reductions in project-related expenses and increased profits. In the end, the owner ultimately reaps the economic rewards of a BIM process and workflow.[23]

The acronym "BIM" historically links in many minds to 3-D and now 4-D and 5-D virtual modeling of buildings. Used within this scope, BIM speaks primarily to architects, engineers, specification writers, estimators, scientists interested in performance modeling, constructors and construction vendors, computer application vendors, and owners. The future of BIM modeling should expand the information model to include more life cycle phases (such as real property commerce, maintenance and operations, environmental simulation) to standardize life cycle process definitions and associated exchanges of information. In addition, BIM models need to standardize information content to ensure clear and consistent meanings and granularity. This expanded scope makes BIM useful to a wider community including real property managers, appraisers, brokers, mortgage bankers, facility assessors, facility managers, maintenance and operations engineers, safety and security personnel, incident responders, landscape architects, infrastructure engineers and operators, and others associated with new building design and construction.

Although BIM applications and practices in current use compare superior to manual and 2D-only CAD methodologies, current usage of BIM technologies and

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[22] Eastman, Charles M., et al, BIM Handbook, 2008, 11.
[23] Smith, Dana K., and Michael Tardif, Building Information Modeling, 2009, 19-20.

techniques must continue to improve. Currently, processes and content remain on a project-by-project basis. To realize necessary end-to-end efficiencies in the capital facilities industry, BIM methods need machine-to-machine and application-to-application exchanges and characteristics.

Current Trends

BIM embodies a recent technology and process shift within the AEC industry. This process encourages streamlining project development and collaboration. Development rooted in CAD-based research and technology starting in the late 1970s and early 1980s.[24] Unlike CAD platforms, which utilize vectors to define fixed geometry (2-D and 3-D), BIM represents 3-D objects based on parameters and rules, which determine geometry and associated data. These parameters and rules apply to relationships between objects. For example, BIM restricts door placement to a wall, and the object automatically deducts the void created in the wall from the overall wall area. Parameters allow automatic updates to modifications. CAD-based systems require manual modifications and updates in multiple drawings and views, a time-consuming and error-prone procedure.

The increasing development and adoption of specialized BIM software packages allows for distributed building information models. Perhaps the largest contributing factor to this trend derives from the fact BIM tools can be very powerful and expensive. To burden each AEC group with unnecessary software complexity and added costs seems senseless. Contracts increasingly demand, address and encourage the use of BIM workflows. Issues regarding liability, risk, scope of work, and information ownership become increasingly important. Another related trend involves redefining roles and the

[24] Eastman, Charles M., et al, BIM Handbook, 26-29.

development of new skills. Slowly, modeling skills continue to replace drafting skills in design practices. On a larger scale, project teams recognize the benefits of early design input from a broader array of stakeholder groups through the utilization of BIM. These benefits result in the formation of new partnerships at a faster rate.

The development of national and international BIM standards helps define best practices and guidelines for leveraging technological benefits. The solidification of BIM performance and expectations in the building industry coincides with increasing demand by public and private agencies for 'greener' and more sustainable buildings. BIM developers consistently add new features to assist AEC groups to quantify and analyze modeling data. In addition, more BIM models perform design checks and demonstrate code compliance.

National BIM Standards (NBIMS)

The National BIM Standard (NBIMS) Committee, a committee of NIBS, works to knit together a broad and deep constituency for addressing the losses and limitations associated with errors and inefficiencies in the building supply chain.[25] The current NBIMS Charter signatories[26] represent most of the active end-user constituencies, as well as many professional associations, technical and associated services vendors who support NBIMS.

Several organizations have initiatives to develop data technology, generic business process workflows and content standards. As one of the most important tasks, NBIMS coordinates these efforts and harmonizes work between all organizations with similar products and interests. Many professional organizations provide subject matter expertise and important development resources. Most BIM application vendors indicate

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[25] NBIMS website
[26] NBIMS website

support for BIM standards and participate in an advisory capacity and through test bed demonstrations.

NBIM standards merge data into interoperability standards, content values and process definitions to create "business views" of information needed to accomplish a particular set of functions, as well as the information exchange between stakeholders. This standard differs significantly from previous initiatives that centered primarily on data-centric approaches. Using these business views as guides, NBIMS standards identify information needed to support those views, appropriate content standards, and provide a technical description developers use to provide supporting computer-based applications.

To illustrate these business views, some of the distinguishing characteristics and goals for the Committee include numerous points. The scope and planned products represent more practice-oriented rather than data-centric views. Organization and representation on the Committee reflect this intent. The Charter assumes and encourages participants from all phases of the building process lifecycle. A primary goal extends value for all process participants involved in the building lifecycle. The primary strategy maximizes existing research and development through alliances, cross-representation, active testing and prototypes, and an open, inclusive approach to membership and results. NBIMS recognizes and harmonizes work with other standards-development organizations. This committee actively seeks more involvement from private owners, AEC practitioners, property and facility managers, and real property professionals. The Committee supports the view that a building process lifecycle exists not only as a strictly linear process, but also as a primarily cyclical process with feedback and cycle-to-cycle knowledge accumulation. A business process helix with a central knowledge core and external nodes representing process suppliers and external consumers embodies the best representation of the building process lifecycle. "Information interchange synapses" exist between these elements and require exchange rules and agreements.

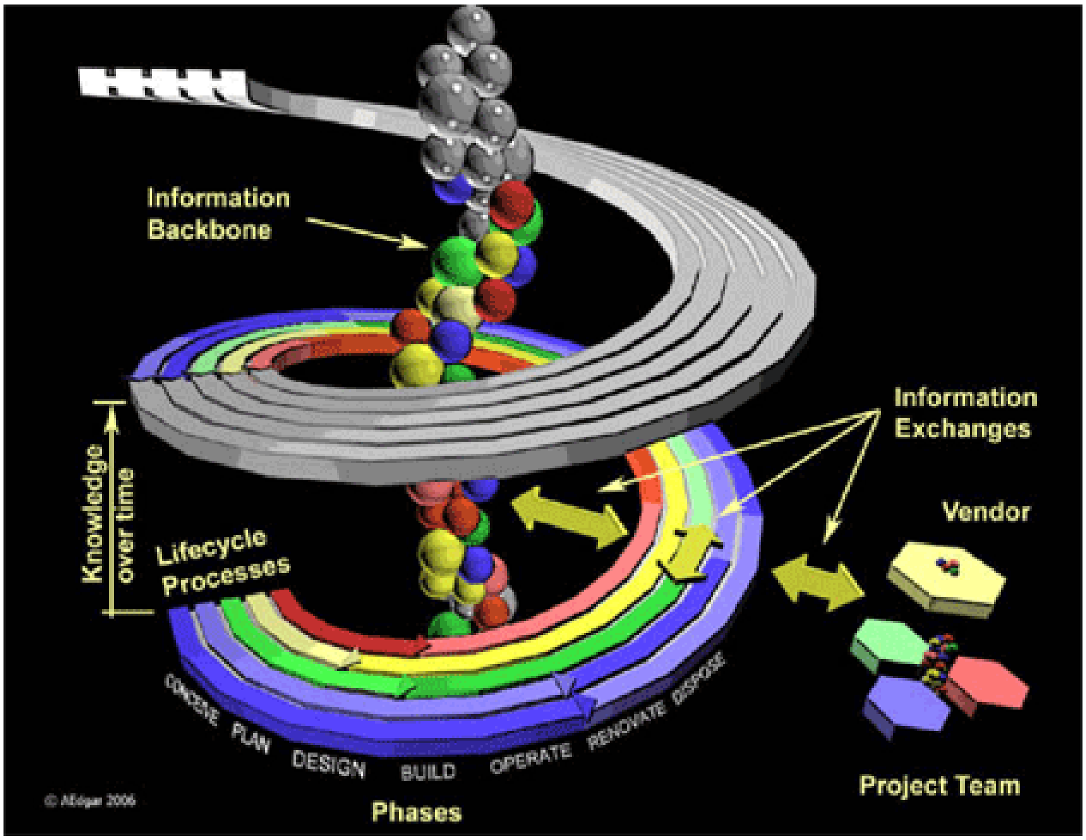

Figure 2.3: A helical building process lifecycle model (NBIMS)

As one of the principal products, standards prescribe parties to a process and contracted information exchange requirements between parties. An interoperable supply chain requires about 250 process definitions. Through a spiral development process, developments release in packages for immediate use as each release adds more mature concepts and practices. The first packages became available in late 2006.

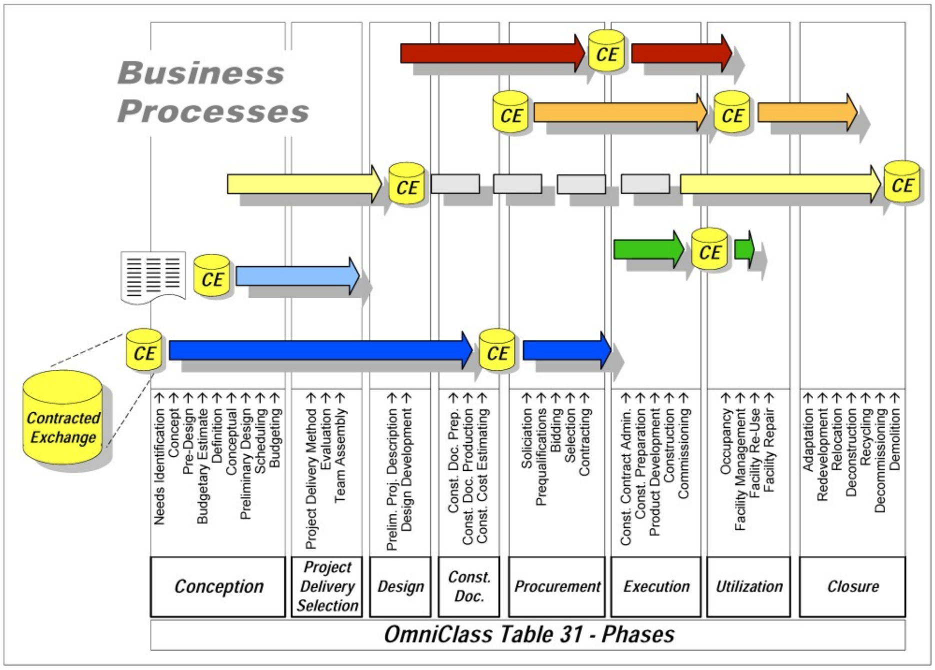

Figure 2.4: NBIMS scoping diagram showing business processes and exchanges on a backdrop of lifecycle phases (© NIBS 2006)

NBIMS supports the development of content standards, including taxonomy standards such as CSI OmniClass, which provides organized classification of elements important to the building process lifecycle. NBIMS recognizes and facilitates the harmonization of software implementation views. These views provide necessary "machine interpretable" data sources to the process of building information exchange. Other examples of software implementation views include buildingSMART™. Vendors actively participate on the Committee for the value of consistent and predictable processes to apply technical solutions. Development, marketing and maintenance of products to support multiple, inconsistent processes, content, and interchange methods proves expensive and complicates the product development cycle. Although not a CAD standard, NBIMS addresses CAD graphic and non-graphic information and processes, as well as phases before and after design and construction. However, the National CAD

Standard continues to be important, as building processes continue to need standards for 2-D drawings and to define standard reports from a model.

The work of the NBIMS Committee represents the next logical step to transform the building supply chain. The standard assumes a required paradigm change, since the definition of paradigm change states, "reforming the underlying pattern or model on which actions are based." Participants in the building supply chain, through standards development and use of existing BIM technologies, are well on the way to changing the underlying patterns and operating practices used during the building lifecycle. To realize the greatest efficiencies, BIM approaches must use broad aggregations of best practices rather than narrow, project-specific, proprietary solutions. New levels of quality and efficiency obtainable through the concentration on the business view of contracted information exchanges and best use of interoperable data sources, and by expanding the conceptual scope of BIM to include all phases of the building lifecycle.

BIM as a Standard and BIM Libraries

BIM tools differ from CAD tools in the same way a slide rule varies from a computer or a set of toy soldiers contrasts to a battle-oriented computer game. BIM supports online simulation of a design and online simulation of construction. These simulations refer to models that incorporate time or cost. BIM enables users to simulate building operations mechanically as well as the people organizations within the facility. The BIM processes provide better building products at lower costs to the owner. A growing number of case studies show the benefits of users who have created a building model to apply BIM technology. Building models and BIM technology will certainly become the standard representation and practice for construction in the near future.

To scope the inter-relationship of projects as well as define the overall range of projects to define a Building Information Model, BIM requires structure. No end exists to the effort and understanding of the product required to collectively develop without such a structure. Based on work to date, developers and users have generated a map of the scope and structure of BIM. The logo for buildingSMART International contains four interlocking squares symbolizing the interoperability needed throughout the facilities industry. Each of those four squares identifies life cycle aspects of the industry and the basis for vision. While there are currently many ways to describe the life cycle of a facility, all definitions and thoughts link back to this universal structure.

One common misconception: use CAD for 2-D design and BIM for 3-D design. Since CAD technology easily creates 3-D designs, the misconception proves inaccurate. The main difference between CAD and BIM derives from how an object perceives itself after placed within a model. For instance, to draw a wall in CAD, a user may possibly draw one line then copy parallel that line a certain distance to achieve a wall with thickness. Upon windows or doors placement into that wall, the user must break the lines and perform some housekeeping to create openings. If the walls or doors have to move later in the design process, the wall lines require reconnection and a creation of a new opening. With BIM, objects represent simulations of building components. These objects understand the characteristics associated with the objects. In BIM, a wall knows the object placed represents a wall. The wall object contains information about materials, fire rating and height, just to name a few characteristics. When placed into a wall object, the door object allows the automatic creation for the opening in the wall. If the door must move, the software fills the previous wall opening and creates an opening in the new location.

BIM Saves Money

How often has a design in CAD seemed sound, but during construction, problems arose and resulted in costly changes? With BIM, the developed model accurately reflects the elements for construction. Interference detection allows analyses on the model prior to construction. For instance, a designer could determine where beams conflict with other beams or where ducts interfere with pipes. The preferred discovery of these problems would occur during the design phase rather than the construction phase. BIM makes the discovery during design possible. Besides interference detection, BIM technology provides functionality for animation, analysis, drafting, modeling, plotting, simulation, and visualization. One key aspect of BIM allows for collaboration amongst engineers and architects on a scale not previously possible.

Right now, one may be thinking, *"Great! Now I must learn something new. Guess all my CAD skills will go to waste."* This statement could be no further from the truth. Throughout the use of BIM software, users constantly use tools from the CAD software set of tools. Also after the creation of a BIM model, all extractions derive from the model. These extractions create model files and sheet files. Once at the stage of assembling construction documents, project teams employ CAD skills 100 percent.

Available BIM Technologies

There are many BIM design software platforms currently available for AEC professionals; however, no "one-size-fits-all" platform exists or works for all projects or all design team participants. Current capabilities and initial costs should not comprise the basis for the purchase of a BIM platform. Consider the purchase as an investment to involve future evolutions, new content and file type generation, and continuous user training. While dozens of BIM-capable software tools exist for industry stakeholders, this research concentrates on the BIM tools currently used by AEC professionals. The following authoring tools represent the majority of current BIM adoption in the US. Each tool contains descriptions in terms of current release, operating platform, user interface, product family, file organization, interoperability, extent of parametric component library, and scalability.

Autodesk Revit Architecture represents one of the most widely used BIM tools for AEC design.[27] Autodesk makes the current version release, Revit Architecture 2012, available only to Windows operating systems. Relatively easy to learn, the program contains accessible and intuitive tools to use for project workflows. Significant improvements include refinements to free-form modeling and conceptual design environments. In addition to 2-D drawing and 3-D modeling views, the software features a high-quality rendering engine within the program. With per seat licenses starting at $5,495 for an annual subscription, the vendor offers this software within a suite of other software packages to offset the expense.[28]

The Autodesk BIM suite includes Revit Architecture, Revit MEP (Mechanical, Electrical, Plumbing), and Revit Structure, which cater to major AEC industries. Autodesk recently acquired Ecotect as its comprehensive energy-modeling tool. Revit uses a central library database structure for storage and linkage of information. The suite supports the import/export of various files types including BMP, CAD, DGN, DWF, DWG, DXF, JPG, JPEG, PNG, SAT, SKP, STL and TIF. The software supports model analysis exports to ADSK, FBX, gbXML, IFC, and ODBC. Revit contains an extensive object library, referred to as “families,” predominantly developed by third-party vendors. For data between the information database and model views, Revit supports bi-directional exchanges. Revit uses an “in-memory” system, which means information must be loaded

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[27] Eastman, Charles M., et al, BIM Handbook, 57.
[28] http://store.digitalriver.com/DRHM/store

into the project file for use in the model. This system makes project files very large, and as a result, performance may suffer. Performance degrades especially when dealing with server-based collaboration.

Bentley MicroStation provides a wide range of solutions for AEC industries, including bridges, buildings, campuses, communications, factories, government, mining and metals, process manufacturing, power generation, rail and transit, roads, utilities and water and wastewater. The buildings category comprises a family of products including Architecture, GenerativeComponents, Structural Modeler, Building Mechanical Systems, Building Electrical Systems, Facilities, and ProjectWise Navigator (for multi-project and multi-user collaboration). Bentley makes the current version release, Bentley Architecture V8i, available only to Windows operating systems. With a single seat license cost of $6,290 to non-MicroStation users, Bentley includes MicroStation, passport for ProjectWise Navigator, Parametric Cell Studio and Space Planner and Bentley Architecture to offset the expense. MicroStation users may add Bentley Architecture as an upgrade for $1,495.[29]

With a large and non-integrated user interface, Bentley Architecture proves difficult to navigate and learn. The software features relatively fast conceptual design modeling and space planning capabilities. The software also highlights a powerful rendering engine for the production of high-quality images and animations within the application. Bentley Architecture supports import/export formats including DGN, DWG, DXF, IFC, IGES, PDF, STEP and STL.[30] The software also supports native Rhino and SketchUp model formats.[31]

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29 http://aecbytes.com/review/2009/BentleyArchV8i.html
30 Eastman, Charles M., et al. BIM Handbook, 58.
31 http://aecbytes.com/review/2009/BentleyArchV8i.html (19 November 2009).

The software contains a relatively small parametric object library. Bentley Architecture features a distributed file structure to help manage large projects. This type of file organization makes setup and management difficult.

Nemetschek North America Vectorworks owns a small and growing market share in the US AEC industry. With various industry-specific versions, Vectorworks offers Architect (AEC BIM authoring tool), Landmark (landscape and site design), Spotlight (theatrical and exhibit design), Machine Design, Fundamentals (non-industry specific version), and Designer (includes all industry tools, commands, and objects). All versions function with or without Renderworks, a presentation-rendering tool. Nemetschek makes the current Vectorworks version release, 2012, available to Windows and Macintosh operating systems. Vectorworks Architect costs $2,395 for each seat license and $400 for an upgrade license (Windows and Macintosh).[32]

Vectorworks contains extensive data-rich object libraries and allows for a wide variety of user-created content through its VectorScript programming language. The software lacks certain building-industry specific BIM software for mechanical, electrical, plumbing and structural elements. File-based as opposed to server-based, work share solutions prove adequate for small firms, but cause limitations on scalability and real-time collaboration among multiple users.

Graphisoft ArchiCAD (owned by Nemetschek) represents the oldest BIM design tools available on the market.[33] Graphisoft makes the current version, ArchiCAD Version 15, available to Windows and Macintosh operating systems. ArchiCAD costs $4,250 per seat license, and Graphisoft provides an upgrade to existing users for $895.[34]

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32 https://secure.nemetschek.net/estore/architect.php.
33 Eastman, Charles M., et al, BIM Handbook, 59.
34 www.aecbytes.com/review/2011/ArchiCAD15.html.

The user interface proves relatively simple to manipulate and contains an intuitive workflow. Graphisoft offers various extensions for ArchiCAD, including Artlantis (high-quality rendering), EcoDesigner (for energy analysis), MEP Modeler and Virtual Building Explorer (interactive 3-D presentations). Graphisoft offers a more economical and lightweight BIM software called ArchiCAD STAR(T) Edition for approximately $2,000 per seat license.[35] Specifically designed for small architecture firms, Graphisoft provides this software with limited features for modeling, visualization, collaboration, performance, and project organization.

Although Graphisoft lacks a dedicated structural BIM application, interfaces work with a variety of other proprietary structural tools, including Revit Structure, Scia Engineer and Tekla Structures. ArchiCAD supports various third-party "add-ons" to extend the functionality of core BIM tool capabilities. Similar to Revit, ArchiCAD manages model information through a centralized database. The software supports import/export file formats including DGN, DWF, DWG, DXF, and PDF. ArchiCAD also supports model data export to ARCHiPHISIK, gbXML, DOE-2, IFC, OBDC and RIUSKA. The tool supports direct links to Cinema 4-D (3-D animation), Google Earth and SketchUp software. Like Revit, ArchiCAD uses an 'in-memory' system, which presents scalability issues for large projects. To make the models manageable, ArchiCAD partitions the models into smaller modules. For easier and faster collaboration on large projects, Graphisoft developed the first BIM Server application.[36]

ArchiCAD possesses certain parametric modeling limitations in terms of automatic updates between objects.[37] The package lacks modeling constraints and does

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[35] www.graphisoftus.com/products_promos.php.
[36] www.aecbytes.com/review/2009/ArchiCAD13.html.
[37] Eastman, Charles M., et al. BIM Handbook, 59.

not support association between modeling elements, which causes problems with other analysis tools.[38]

In summary, the above BIM tools each possess advantages and disadvantages, especially in terms of cost, learning curve, capacity, and interoperability. As the rate of BIM adoption increases and vendors continue version updates, market shares and software features inevitably improve and diversify. This diversification of BIM tools prevents a single proprietary BIM developer from controlling the entire AEC market. Industry stakeholders must determine the appropriate tool or software suite for specific project types and collaboration requirements.

The Future and Rethinking BIM Utilization

Several predictions of future trends exist with regard to BIM use in the AEC industry. These trends include changes in workflows, contracts and regulations, and services and roles. The following sections briefly described each of these major trends.

Workflows will shift from sequential efforts to parallel actions. BIM and IDP allow for earlier collaboration and information exchanges that can occur simultaneously. BIM model information will continue to serve multiple purposes while reducing the need for duplication and redundancy. Fabrication processes based on BIM will become increasingly standard as software interoperability improves. More opportunities will arise for scenario planning and iterative analysis to measure and test various design options. Energy modeling develops into a standard (if not required) aspect of BIM tools as performance-based standards replace prescriptive standards. BIM models will collect and track data on both micro (per building) and macro scales (per municipality). The combination of BIM and GIS data sets will become seamless. BIM models will verify

[38] www.aecbytes.com/review/2009/ArchiCAD13.html (30 September 2009).

code compliance through plug-ins or external programs. The use of 3-D digital models during design and construction will continue to make paper-based drawing sets obsolete. Perhaps the greatest workflow shift (unrealized) involves using BIM as a communication tool as opposed to a production tool. The perception of information will change from something for delivery as a final product to something leveraged and updated over a long period.

Contracts will adjust for liability and compensation issues among project team stakeholders. Depending on the situation, agreements will become more explicit and flexible. Fragmented design-bid-build relationships between owners, contractors, and architects will become less popular in lieu of closer design-build relationships that utilize BIM more efficiently. When using BIM, governing authorities or project teams need to address various questions, such as:

- *Who has access to the BIM model?*
- *Who owns the BIM model after the project constructed?*
- *Who becomes responsible for information once added to the BIM model?*
- *Who pays and assumes responsibility for tools that overlap industries or are non-industry specific (phasing, analysis, and server collaboration)?*
- *What information workflows will be used between specific groups and at what time in the project timeline?*
- *What process tracks and bills project time?*

As services and roles shift and continue evolution, over time, BIM will gain higher adoption among companies. The greatest changes are likely to occur in design firms, which have been the slowest to leverage the benefits of BIM tools. Design staff will be required to have proficiency using BIM (similar to CAD proficiency as the norm for well over a decade). Staff will be downsized for documentation-related tasks as new management roles, such as BIM manager, BIM modeler, and BIM leader, become commonplace. These roles will replace similar CAD standard and management positions. There will be an increase in BIM modeling and analysis specializations as building systems and materials become more complex. Firms will be able to provide additional services as companies realize the potential to leverage BIM model information.

The greatest question concerns the quality of BIM data 10, 20, and 30 years from now. Vendors market BIM software as a long-term building life cycle management tool; however, buildings last far longer than data and causes an underlying problem. Another problem with enduring data structures and file formats revolves around the potential impediment to interoperability improvements. The best-case scenario involves some form of open-source data format, which would remain consistent over a long time. Proprietary BIM developers present an obvious barrier to this option. Of course, these developers have no desire to utilize assets and resources that could potentially put the developers out of business. This conflict poses an ongoing dilemma, which requires careful research and planning by both BIM users and developers.

SUMMARY OF LITERATURE REVIEW

While CAD remains an excellent design tool, BIM technology allows the reuse of information throughout all phases of the life cycle of a structure. BIM allows for time and cost savings CAD technology cannot realize. Companies can no longer maintain BIM as an option; the implementation of BIM technology represents a present necessity.

Chapter 3: Study Methodology

The following research involves the topics of BIM and disruptive technology within the context of perspective of socially and historically situated simulation and case studies.[39] This chapter presents the collection and interpretation of data through the lens of multiple realities shaped by the social and historical context in which each respectively belongs. Therefore, the relationship with the knowledge collected and presented here is interactive and not absolute. The importance of this relationship reveals the basic beliefs and assumptions inherent in the research. The goal of choosing certain research methods assists in triangulating data to validate conclusions and recommendations for improving project development using BIM. Each methodology contains strengths and weaknesses; however, the combination of multiple approaches minimizes the weaknesses and improves the strengths.[40] The following research is the result of both qualitative and quantitative data collected from two primary methodologies: case studies and literature reviews.

This chapter, which consists of three distinct sections, presents the research methods of this study. The first section explains the context of the empirical study. The second section describes the data collection methods, together with the chosen research approach. The third section presents the data analysis methods.

CASE STUDIES

Groat and Wang suggest basing the choice of multiple versus single case studies on the nature of the research question(s) and the role of application or replication.[41] Based on the relatively broad research question, the best approach involves in-depth

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[39] Groat, Linda N., and David Wang, Architectural Research Methods, New York, J. Wiley, 2002, 32-41.
[40] Groat, Linda N., and David Wang, 361.
[41] Groat, Linda N., and David Wang, 356.

research of a single case study to help uncover the social and historical contexts and stakeholder relationships otherwise not practical by conducting multiple case study comparisons in the same period.

The case study method allows researchers to understand complex phenomena based on real-life events.[42] Case studies involve single or multiple cases. The single case study enables analysis of the implementation of BIM in a complex project environment, where the new technology affects multiple stakeholders. The case study involves a new design project for the renovation of two military intelligence facilities at Goodfellow AFB in San Angelo, TX. In general, the purpose of the case study approach concentrates on understanding the dynamics present in single settings.[43] According to Yin, the case study method becomes advantageous when asking a "how" or "why" question about a contemporary set of events over which one possesses little or no control.[44] Furthermore, the case study research approach proves especially appropriate in new topic areas that lack scientific knowledge.[45] Literature only recently acknowledges a process perspective to BIM.[46] The case study approach brings forth new knowledge about the implementation of BIM from this little researched perspective.

Within single case studies, researchers utilize single or multiple units of analysis.[47] The latter method, or embedded design, allows the use of multiple levels of analysis within a single case.[48] This section presents processes at the level of the building project and the level of the firm. The first research question examines the needed process

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42 Yin 2003, 2
43 Eisenhardt 1989, 534
44 Yin 2003, 9)
45 Eisenhardt 1989, 532
46 Harty 2005; Taylor 2007; Taylor & Bernstein 2008; Taylor & Levitt 2007
47 Eisenhardt 1989, 534
48 Yin 2003, 40-43

changes in the project level, and the second research question studies the implications of these changes to the business processes of the owner. Owners mandate BIM delivery systems, which makes the effects of the BIM delivery system interesting.[49] The observation of the interaction of processes between two different levels proves theoretically valuable. The opportunity to use multiple data collection methods, for example archives and observations represents a major strength of the case study approach.[50] This research utilizes project documents and observations to achieve data triangulation.

Critics say case studies lack systematic procedures and researchers allow equivocal evidence or biased views to affect findings and conclusions.[51] In this research, the use of multiple data collection methods attempts to avoid these weaknesses in the case study approach. Systemically analyze the data as a way to deal with these problems. Critics assert case studies provide little basis for scientific generalization. Yin responds to this critique by stating case studies provide analytic generalization instead of statistical generalization, which means the expansion of theories. Case studies take too long to perform; result in massive documents; and without a clear application, the amount of data overwhelms researchers.[52] However, the single case study approach enables data gathering in a relatively short period and makes the volume of data manageable. In addition, the process perspective of the study allows concentrating the research and managing gathered data.

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[49] Hannon 2007, 2
[50] Eisenhardt 1989, 534 and Yin 2003, 97
[51] Yin 2003, 10
[52] Yin 2003, 11 and Eisenhardt 1989, 536

The Implementation of BIM

BIM changes the traditional phases of building projects. For this reason, the naming of specific project phases poses potential confusion. Nevertheless, based on project documentation, projects typically divide into five phases: needs and objectives; conceptual design; early design; detailed design; and construction and commissioning stage. Figure 4.1 illustrates these five phases and the general content of each phase stressing BIM related issues.

The needs and objectives phase analyzes the needs and objectives of the end-user. This phase determines the overall spatial needs of the end-user and the requirements of the spaces for operations. Spatial programs describe the areas of different space needs. After the creation of the preliminary spatial program, the architect fits the spatial program onto the project site. The site plan uses a spatial group model, the first building information model for use in the project. The creation of the spatial group model begins the conceptual design phase. The purpose of the conceptual design phase develops the basic design solutions of the project. The architect shares the spatial group model with the owner and the end-users for comments on the division of different spaces. The discussions help to specify the preliminary spatial program from the latter portions of the needs and objectives phase. At this phase, building masses change because of master planning issues.

Based on the spatial program, cost estimators formulate the construction costs. The cost estimator uses the areas and volumes of the building, defined in the spatial program, as the basis of the estimate. Simultaneously, the architect continues development of the spatial group model into a spatial model and a preliminary building element model. These models analyze different alternatives for the project. At this stage of the conceptual design, the designers perform energy simulations to evaluate the energy efficiency of the building. The energy simulations show the energy consumption of the project. Therefore, if the energy simulations result in less than optimal operation, the team changes the design to achieve energy targets.

At the end of conceptual design, designers negotiate the improved spatial program and structure of the project with the owner and end-users. The end-users make a preliminary lease with the owner, and the owner decides to invest in the project. The conceptual design phase contains several unique features the owner did not use in previous projects. These features exist because the owner wants to investigate the benefits of more design work through modeling before the investment decision. At this point, the design team performs energy simulations to optimize the energy consumption of the project.

In the beginning of the early design phase, the owner chooses a project consultant to manage and coordinate the rest of the project. As the first task, project consultant creates a project plan. In the early design phase, the basic design solutions develop further. The architect continues to work on the preliminary building element model from the conceptual design phase. The preliminary building element model develops into a building element model as the level of detail increases during the early design phase.

During the early design phase, designers define targets for the project. These target formulate form the wishes of the end-user. This information enables designers to identify requirements for the necessary systems. In the end of the early design phase, designers create a preliminary model for the systems in the project. The greatest benefits derive from the early involvement of necessary subject matter experts and designers. Each designer follows the same process as the architect.

The collaboration among designers remains highly interactive during the early design phase. Designers frequently consult one another. For this reason, the workflow between designers presents a difficult process to describe. Nevertheless, the process distinguishes few important collaborative acts. The architect and other designers perform one such act from the formation of a spatial reservation model. This model illustrates the space need of various systems. The review and merging of models between designers represent another important collaborative effort. These efforts enable the designers to check the models for conflicts and to discuss and correct problems. The end of the early design phase triggers application for appropriate permits and the approval of design solutions.

In the detailed design phase, the accuracy of information increases so that construction may commence. Designers add more detail information to the models. The architect increases the accuracy of the building element model, designers develop system models, and engineers develop a building element model. The final lease between the end-user and the owner signals the end of detailed design. At this point, the owner decides to begin construction.

During construction, the designers make alterations and supplement the design of the models as necessary. For building contractors, daily use of the model represents the most useful tool. The building contractor utilizes the model to schedule construction. Manufacturers use these models as the foundation to produce reinforcement bars. The manufacturer of these reinforcement bars feed the model information to machines that produced the bars. When the construction finishes, the owner and end-user examine, approve and commission the project.

The processes above represent a single project. Different types of projects require different starting points. In addition, designers may define or name the phases differently. In reality, the lines between the phases overlap. Because the implementation of BIM remains a gradual process, the phases and content present an unspecified area for building construction processes. Traditional work processes persist with new processes starting to emerge.

Description of the Empirical Data and Data Analysis Methods

This section explains the content and role of each data type. December 2010 marks the start of the data gathering process. This data derives from project documentation produced during the project. The documentation includes project schedules, records from design team meetings, records from the site meetings, and building information models. The project documentation generates a general view of the project progress. From this documentation, the design team creates a preliminary process model. This preliminary process model provides a means to memorize the building processes and allows improvements.

In addition, the data references the implications of the changing project processes regarding the business processes of the owner. Eisenhardt (1989, 539) notes one strength of case research allows adjustments to the data collection process to study specific emerging themes. The purpose illustrates the linkages between the BIM project processes and the investment process of the owner. The owner investment process guides the completion of projects. In addition, BIM guidelines show the relationship between the guidelines, the building processes and the business processes.

According to Strauss and Corbin, qualitative research consists of three major components: the data, analytic and interpretative procedures to arrive at findings or theories, and written and verbal reports.[53] This section explains data analysis methods.

The challenge of qualitative research "is to make sense of massive amounts of data, reduce the volume of information, identify significant patterns, and construct a

[53] Strauss and Corbin, 1990, 20

framework for communicating the essence of what the data reveal."[54] Guidelines assist in the analysis of qualitative data.[55] The following sections describe the use and adoption of these guidelines to report the analytical processes and procedures when interpreting the empirical data.

Qualitative data consists mainly of words, which contain multiple meanings and depend upon the words that precede and follow. This context makes qualitative data analysis a challenging factor.[56] A common solution uses coding field notes, observations, and archival materials to analyze qualitative data.[57] The process of coding, or content analysis, means the "process of identifying, coding, and categorizing the primary patterns in the data."[58] Strauss and Corbin identify three major types of coding: open coding, axial coding, and selective coding.[59]

Open coding refers to the process of breaking down, examining, comparing, conceptualizing, and categorizing data. The data identifies and groups the codes into more abstract categories. Axial coding means reconstructs the data in new ways after the completion of open coding. This reconstruction connects categories. The purpose of axial coding identifies linkages between a category and subcategories to develop main categories of the data. Selective coding comprises the process of selecting the core category and systematically relating the core to other categories. Selective coding integrates the data around a central phenomenon.[60] A single session allows for different

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[54] Patton, 1990, 371-372
[55] Patton, 372
[56] Miles & Huberman, 1990, 54
[57] Miles & Huberman, 56; and Strauss & Corbin 1990, 57
[58] Patton, 381
[59] Strauss and Corbin, 1990, 61-142
[60] Strauss and Corbin, 61-142

types of coding, although the different types of coding procedures may not occur sequentially.[61] The lines between each type of coding occur artificially.

As a result, the four Taylor and Bernstein (2008) paradigms comprise the main categories in the analysis. The original categories remain as subcategories within the four main categories. However, Taylor and Bernstein (2008) could not fit all categories originally identified under the four paradigms. To acknowledge issues not linked to the four paradigms, a fifth group forms. This group, or facility management, emerges as a new paradigm.

This analysis process identifies benefits derived from the use of BIM under five groups. These groups consist of visualization, coordination, analysis, supply chain integration, and facility management. This approach enables the discovery of how certain process changes contribute to the benefits. In addition, the analysis process classifies the implications of project-level process changes in the business processes of the owner. Chapter 4 discusses the findings of the data analysis.

Interoperability

Interoperability or compatibility reveals barriers or opportunities stakeholders encounter when implementing BIM. This research investigates the degree to which Revit software relates to other software programs and file types. Since information technology changes rapidly, this investigation relates to Revit Architecture 2012, other software programs and file formats available during the fall of 2011.

Much of the emphasis on interoperable BIM software orients around large AEC industries completing large and complex projects. With the case of Revit, for example, the software platforms include Revit Architecture (architects), Revit Structure (structural

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[61] Strauss & Corbin, 1990, 58

engineers), and Revit MEP (for mechanical, electrical, plumbing engineers). Autodesk markets its BIM software suite along with a list of other compatible tools, such as AutoCAD, AutoCAD Civil 3-D, 3-D Max Design, Ecotect Analysis, Navisworks, Quantity Takeoff, Buzzsaw, and Constructware to name a few. In reality, small-scale AEC industries may not need to use these additional tools because the projects lack complex structural, mechanical, electrical, and plumbing (MEP) systems. The use of additional software tools in this case proves unnecessary and becomes potentially cumbersome to small-scale projects.

Common programs and file types used to communicate design information include AutoCAD (DWG, DXF), Adobe Acrobat (PDF) and Microsoft Word (DOC/X) and Excel (XLS/X). Information workflow categories include drawings, specifications, and cost estimates. Information suggests small-scale and small-project AEC groups use "low-capacity" software platforms, meaning simple to learn and use tools (contrast to BIM tools, for example, considered "high-capacity" tools based on the developed products and the additional learning curve involved to effectively use).

To combine specifications within the BIM model and link the information between components and text fields, Revit Architecture requires multiple references and associative work (proves too expensive for the project). The modeling environment supports the copying/pasting of text between Word and Revit. However, this process complicates document formatting and does not easily print multiple page specifications. In addition, the link project information between the specification text and the model components (such as door or window types, and manufacturer information) proves a challenge. This lack of integration treats specifications as separate documents and requires manual updates to match the model. In this situation, the opportunity misses the mark to streamline information workflows.

Another attempt at compatibility links quantity takeoffs from Revit to an Excel spreadsheet. These quantities allow contractors to accurately bid and procure materials. This process proves another challenge to designers. Revit Architecture contains an export format to link Microsoft Access. The drawback to this export function stems from the data containing all the BIM model information, which makes data organization difficult to navigate or isolate. Revit quantity schedules appear in a different format in the Access file. Contractors tend to find the information unusable in a simple Excel spreadsheet format for contractors to bid projects and procure necessary materials. Although the software provides this information, the process does not represent a preferable means to streamline information workflows between AEC groups.

The results of investigating interoperability and compatibility between Revit and other software platforms indicate strong workflows between “high-capacity” programs (such as Revit to Quantity Takeoff). However, room exists for improvement to streamline information workflows with “low-capacity” tools, especially those tools oriented towards small-scale and small-project AEC groups (for example, Revit to Word and Excel).

Quantity Takeoffs

The next task extracts quantity and/or material takeoffs from the BIM model. This process creates accurate “hard” cost estimates, rather than the reliance on manual tabulation from drawings and/or images. Revit Architecture makes the process easy and. Material naming assignments allow designers to total material quantities. Designers assign cost data to each material type and Revit tabulates a total price per area or volume. This procedure represents an alternative method to address the lack of a direct link between Revit and Excel.

The only issue of concern with the material takeoff process involves making certain model modifications for visualization purposes. For example, Revit allows the user to "paint" surfaces a different material finish, but this function serves merely for aesthetic purposes and does not associate any quantity/material information. Another potential discrepancy occurs when designers modify a system family profile in Revit (for example, a roof, wall, floor or ceiling). Revit supposedly does not update the added or subtracted area to match the altered profile. As a result, inaccuracies appear in the visual material quantity. If this functionality proves true, logic cautions Revit users against the blind trust of quantitative data derived from the BIM model.

Presentation Renderings, Code Compliance and Visualization

Photorealistic renderings present another benefit of using BIM tools in parametric model. This capability streamlines the design process and allows visualization and documentation from a single model without having to duplicate information for rendering using a different program. By consciously assigning the appropriate materials, sun/shadow settings, and camera views, designers produce a series of high-quality renderings for the project to supplement technical drawing information or as separate images for presentation purposes.

Different building reviewers and inspectors make inconsistent code interpretations. Contractor or architect-provided design information requires clear and consistent content. Otherwise, changes and revisions demand additional time and cost to resubmit deliverables. While government agencies determine building review and inspection processes, an interesting topic examines how BIM tools demonstrate code compliance and assist with implementing a consistent review process.

Based on literature reviews, code compliance measures do not exist in current BIM platforms. Integration of code compliance offers real opportunities with BIM tools. Through the realization of this potential, design teams develop standard BIM templates and/or pre-configured 3-D code compliance objects available for download on websites. This standardization helps shorten project review time and reduces the number of misinterpretations and errors for project development teams.

An interesting aspect of using standardized BIM templates for code compliance, transparency increases between the design and review process and provides greater accountability for architects/contractors. While a positive step forward, this transparency potentially creates controversy between stakeholders. For example, one option requires the design team to apply for a variance; however, this procedure adds cost and time to the review process. Easy to accomplish with CAD-based tools, purposeful misrepresentation proves more challenging with BIM tools because the 3-D model directly links to the referenced 2-D drawings. One potential benefit in this situation requires modified code requirements for a more transparent process.

Construction Documents

Project document comprises the most widely used capability of BIM tools. The 3-D model reference the drawing sheets and represents one of the many benefits of BIM tools in comparison to CAD-based tools. For example, Revit creates model views with a particular scale, detail level, and graphic style. The associative view title, scale and annotations allow users to drag these views onto user-defined drawing sheets.

The timesaving element of the BIM process reflects the fact that any change made to the view on the sheet (in Revit by activating the view), or any change made to the 3-D model, simultaneously updates all associated/referenced data. In addition, users may quickly add or delete views to show desired documentation content. In contrast with non-parametric CAD-based software, a design change requires a manual update to each drawing, which results in a tedious and error-prone documentation process.

Little need to setup or modify line weights for clearly representing drawing information exemplifies another timesaving benefit of using BIM tools for documentation. In Revit, these pre-set drawing conventions automatically adjust based on the view scale on each sheet. From personal experience using AutoCAD, the management of layers, line weights and color-based plot styles wastes precious project time. These elements have nothing to do with *design* and tend to consume time otherwise invested in project development and analysis.

This sentiment seems to embody the larger conceptual shift Revit (and by extension, BIM) presents to users – especially those previously taught to understand buildings through isolated 2-D representations rather than through interrelated and associated 3-D components representing typical construction assemblies. While easy to blame this condition on user ignorance or inexperience, BIM tools present different capabilities. Revit, for example, may not necessarily represent the most intuitive or easy-to-learn software available. The context reveals a telling sign of the difficulty involved with change and improvement to current design and construction practices – especially for small-scale and small-project AEC companies. In comparison to non-BIM tools, this situation illustrates an increase to the learning curve associated with BIM tools. Common learning curve challenges exist in academic and professional environments, which support the need for formal training of BIM tools.

Revit certainly demonstrates easier and faster collaboration and production of construction documentation, cost estimates and energy analysis. However, drawbacks exist to this workflow. For instance, some BIM tools, such as Revit, contain modeling and representation limitations. Ways to "trick" parametric modeling tools such as Revit exist to produce a model to work visually. However, these "tricks" present frustrating and time-consuming solutions when compared to tools like AutoCAD that provide flexibility for line work and patterning. In cases like this, rethink the building design to ease development of models using Revit – clearly an example of an instance when technology drives design decisions for the wrong reasons. Although ideal for BIM tools to provide the flexibility and versatility of vector-based tools, the current development of object-based parameters for BIM models naturally creates restrictions sometimes unanticipated and counterproductive.

LITERATURE REVIEW

The main research method involves performing a comprehensive literature review process. This method entails finding published and peer-reviewed documentation using relevant keywords, including: BIM, parametric modeling, sustainability, integrated project delivery, and stakeholders. This thesis references the findings from available resources.

Chapter 4: Results

This section presents the findings of the study as the findings relate to previously written literature. The chapter consists of three main parts. The first part discusses how project processes develop to utilize BIM efficiently. Four BIM paradigm practices, visualization, coordination, analysis, and supply chain integration, achieve efficient utilization of BIM.[62] In addition, the research identifies the emerging paradigm of facility management. The goal of this examination identifies what kind of benefits the utilization of BIM achieves, and how process development contributes to realizing these benefits. The second section discusses how the process development and project processes influence the business processes of the owner. The third area synthesizes the findings in a model of BIM implementation for the project-based construction industry, which pulls the findings together.

RESEARCH METHODS

This chapter consists of three sections. The first section explains the context of the empirical study. The second section describes the data collection methods, together with the chosen research approach. The third section presents the data analysis methods.

Context of the Empirical Study - Case Description

During the years 2003-2007, GSA launched several BIM pilot projects to utilize BIM technologies efficiently in projects. These projects serve as advanced pilots for the use of BIM and interoperable software solutions in the AEC industry. During this timeframe, GSA provided additional resources for the early adoption of BIM technologies. For these projects, costs estimated based on the building information models and through traditional means.

[62] Taylor and Bernstein (2008)

Stakeholders consist of the following: architect, end-users, consultant, contractors, cost estimators, designers, engineers (civil, electrical, mechanical, plumbing, structural), and owners. In addition to these parties, authorities, BIM consultants, software providers, sub-contractors, and suppliers solve technological interoperability issues during the project. This study emphasizes how the main actors use BIM in projects.

The project requires active end-user involvement throughout the project. In the early stages of a project, the end-user plays an important role in specifying the requirements, spaces and uses for the building. As designs progress, end-users provide comments and guidance to achieve the best possible results. The building owner makes the important decisions concerning the project (such as investment decision, decisions about the type of project delivery, design approvals in different phases. Owner representatives often manage and execute projects. The cost estimator represents an overlooked participant.

If the design team consists of designers from different companies, challenges exist for coordination. Previous experience with BIM plays a definitive role in this situation. In addition to designers, design firms employ BIM experts to aid modeling efforts in the project. The use of BIM remains a rather new issue for building contractors.

BIM changes the traditional phases of building projects. For this reason, naming the project phases presents a difficult and sometimes unclear exercise. Based on project documentation, projects divide into the following five phases: needs and objectives; conceptual design; early design; detailed design; and construction and commissioning stage. Figure 4.1 illustrates these five phases and the general content of each phase stressing BIM related issues.

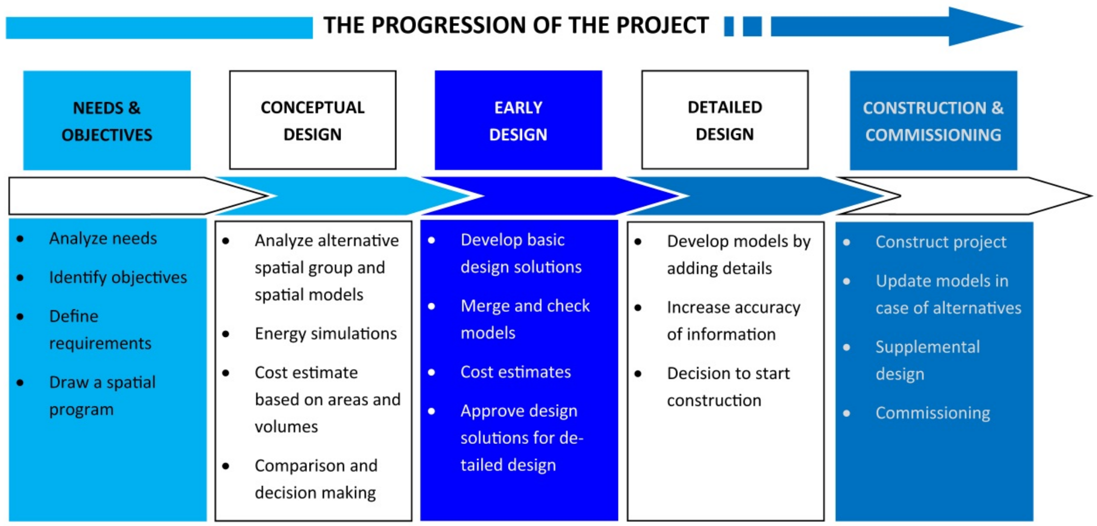

Figure 4.1: Project Phases

The needs and objectives phase starts with analysis of the needs and objectives of the end-user. The purpose determines the overall spatial needs of the end-users and the requirements for the spaces with regard to the operations of the end-user. As a result, a preliminary spatial program develops and describes the areas of different space needs.

After the creation of the preliminary spatial program, the architect starts to fit the spatial program onto the project site. This site plan uses a spatial group model, seen as the first building information model used in the project. The creation of the spatial group model marks the beginning of the conceptual design phase. The purpose of the conceptual design phase develops the basic design solutions of the project. The architect shares the spatial group model with the owner and end-users for comments on the division of different spaces. The discussions further specify the preliminary spatial program from the needs and objectives phase. At this phase, project, or building, masses change because of issues relating to city/master planning.

Based on the spatial program, cost estimators estimate the project costs. The cost estimator uses the areas and volumes of the project from the spatial program as the basis of this estimate. Simultaneously, the architect continues development of the spatial group model into a spatial model and a preliminary building element model. These models analyze different alternatives for the building. At this stage of the conceptual design, energy simulations evaluate the energy efficiency of the building. The energy simulations determine optimal energy consumption. The building structure changes as necessary to achieve energy targets for the project.

At the end of conceptual design, design team negotiates the improved spatial program and structure of the building with the building owner and end-users. The end-users enter a preliminary lease with the owner, and the owner decides to invest in the project. The conceptual design phase contains several unique features for the owner. The main reason for these features center on the desire of the owner to investigate the benefits of performing more design work through modeling before the investment decision. In addition, the owner uses the models to conduct energy simulations to optimize the energy consumption of the project.

At the beginning of the design phase, the owner chooses a project consultant to manage and coordinate the rest of the project. The first task of the project consultant creates a project plan. Early in the early design phase, basic design solutions develop. The architect continues work on the preliminary building element model from the conceptual design phase. The preliminary building element model develops into a building element model as the level of detail increases during the design phase.

Collaboration between designers requires a highly interactive process during the design phase. As a result, designers consult one another frequently. For this reason, the workflow between designers presents a challenge to describe. Nevertheless, a couple of important collaborative acts exist. One such act concerns maintenance of a spatial reservation model by the architect. This model serves as the basis for the rest of the design team and illustrates the spaces needs of the various disciplines. Another important collaborative effort checks and merges models between designers. This process enables the designers to check the models for conflicts and to discuss and correct problems.

According to BIM guidelines, contract tendering normally occurs after the detailed design phase in a separate project phase. Design teams calculate estimates in traditional ways, as well as supplement cost estimates from BIM. The project network leans on traditional practices since the current models do not fully facilitate cost estimates.

Different names and definitions exist for the phases above. Currently, the phases and the contents of these phases require further specification for building construction processes that utilize BIM. The gradual process of implementation for BIM drives additional specification requirements. In addition, the traditional work processes remain in place, with the new processes only starting to emerge.

Process Development to Efficiently Utilize BIM

The literature on BIM implementation and process development emphasizes the need to develop processes when starting to use new technologies. Taylor and Bernstein identify four technological paradigms for BIM and prove their existence quantitatively.[63] However, although the authors stress differences in BIM paradigm across a project network may influence successful utilization of BIM, the authors fail to clarify the difficulties. Firms need to understand the inter-organizational process changes required for each stage of paradigmatic evolution to utilize BIM technologies successfully.

[63] Taylor and Bernstein (2008)

Process development contributes to achieving visualization, coordination, analysis, and supply chain integration benefits when utilizing BIM. In addition to the four categories by Taylor and Bernstein, the research identifies a new, emerging category of facility management.

Visualization

According to Taylor and Bernstein, one of the first benefits from the use of BIM derives from the ability to visualize the designs to project stakeholders. A project network gains additional value from BIM because of the illustrative capabilities of the 3-D model, no matter the individual experience level with BIM. Frequently cited in the data, visualization represents a good way to communicate designs across the project network.

Early, in the conceptual design phase, the architect visualizes plans to the owner and the end-users via a spatial group model. This model reveals the building masses and preliminary position of the main units of the end-user within the facility. Based on this illustration, the architect and the end-users optimize the disposition of organizational units.

The visual 3-D model helps the architect communicate the plans to the end-user. In addition, the end-user provides feedback to the architect, and proper illustrations streamline and ease any changes. These changes, when properly illustrated, allow for easier acceptance. Besides these benefits, the new operational process causes some changes to the traditional process of the architect. In order to visualize the facility to the end-user, the architect needs to create a spatial group model soon after the definition of the needs and objectives of the project. This process change lends itself to minimizing problems as the process influences only the architect, who easily adapts any changes.

Besides the visualization of the architectural model to the owner and end-users, visualization facilitates collaboration between the design team.

Different designers emphasize how the visual 3-D models communicate the design to team members. The models prove especially useful when the designers face troublesome issues and need to check conflicts between the different models. The design team observes conflicts between the models via visual review in design team meetings. However, the designers state automatic clash detection helps to check conflicts between the models. Current software for automatic clash detection produces many insignificant clashes, which makes the entire process quite labor intensive.

In addition to the previously stated benefits, visualization proves useful on the construction site. For example, contractors report the detailed 3-D model of the structural engineer illustrates difficult parts on the construction site. The model helps the actual execution of construction work by facilitating communication of the design plans to the construction site.

The benefits grounded on the illustrative capabilities of the 3-D models provide tighter interaction through better communication and conflict resolution to the project network. Changing inter-organizational processes to achieve the tighter interaction does not seem to cause any significant problems. As Taylor and Bernstein state, projects achieve visualization benefits even if firms perform only a couple of BIM projects. This statement suggests project do not require major process adaptations.

Coordination

Taylor and Bernstein suggest a quick move to the coordination paradigm once companies gain more experience in using BIM. "Using BIM to improve the coordination of work within the firm and across the project network" defines the coordination paradigm.[64] Coordination issues represent the most addressed issues in the data. Use of BIM improves coordination between different project network stakeholders. However, the process causes some coordination problems.

In the case study, the early and detailed design stages achieve most of the coordination benefits from the use of BIM. The main cause for this achievement results from an intensive collaborative use of building information models between the specialist designers. BIM assists the team to merge the models of different designers and check compatibility of the models. However, visual means provides the bulk of this work largely because the automatic clash detection process produces many insignificant clashes. With further development, technologies automate checks for compatibility among different designs.

A spatial reservation BIM illustrates various systems as objects in the architectural model. This approach uncovers trouble spots difficult to identify from 2-D drawings. As models merge, the spatial reservation model observes which elements derive out of the available space. The spatial reservation model helps the design team coordinate work. However, the designers (architect, engineers, and systems designers) need the spatial reservation model early in the process to achieve the greatest benefits. The use of BIM affects multiple organizations simultaneously and creates needs for changes to traditional work practices. Merging models achieves coordination benefits. Comparison of the different models enables the designers to identify clashes and determine appropriate corrective actions.

Despite the benefits achieved in coordinating the work of different designers, the utilization of BIM causes many problems in the inter-organizational processes of the

[64] Taylor and Bernstein 2008

design team. In the early and detailed design stages, many process challenges inhibit the full utilization of BIM. For example, the modeling processes occasionally misalign in the early design phase. This misalignment of the building information model delays the design and forces additional time to merge discipline-specific information. In addition to the misalignment of work, problems face the interface between the architect and other design team members. Without proper coordination, designers guess as to what elements the architect designs.

BIM influences the inter-organizational processes of different project network stakeholders. The design processes vary in design areas, which cause challenges with more integrated work. Thus, a holistic view on the implementation of BIM seems important since the design team knows the processes for specific disciplines.

In addition to the coordination benefits between designers, the construction site achieves advantages by using the 3-D model to schedule and visualize the installation of the various project components. However, the construction site requires prompt delivery of the 3-D model to utilize effectively for simulation of construction activities. Another problem related to the model relates to omissions resulting from the lack of specificity in the contract of the designers. Another challenge appears when contractors continue construction practices in traditional ways. Traditional ways typically avoid use of BIM models.

As Taylor and Bernstein state, the achievement of coordination benefits requires sharing electronic files. This sharing necessitates technological interoperability. Despite the technological challenges, process challenges present the greater concern in comparison to the technological problems.

As a conclusion, BIM technologies integrate the work of construction project networks and facilitate coordination. However, changes in the coordination mechanisms require the development of inter-organizational processes of the design team, as well as between designers and contractors. For this development, a holistic view proves essential to understand the inter-organizational processes of the project network as a whole.

Analysis

Taylor and Bernstein argue that after the coordination paradigm, firms move toward an analysis paradigm. The analysis paradigm relates to the possibilities of evaluating different alternatives and the resultant effects on cost and building performance, for example. While the coordination paradigm concentrates on the coordination of work and improvements to the design and construction processes, the analytical capabilities of BIM improve the product itself.

During the design charrette, the owner, architect, cost estimator, engineers, and other designers communicate the possible benefits in analyzing alternatives early in the design phase. These stakeholders view optimization of the building in the conceptual design phase as the biggest cost-savings. These savings consider both the construction and life cycle costs.

The simulations, based on a preliminary building element model, together with cost estimates, provide information for the investment decision of the owner. Energy simulations determine whether the building meets the preset energy requirements. Consequently, design changes create the building structure in a more energy efficient manner. The alternative building masses and architectural concept designs identify more energy efficient alternatives.

Despite clear benefits, energy simulations present challenges. Completing the energy simulations before the start of the early design phase means the architect must create the spatial model and the preliminary element model. These models form the basis for analysis earlier in the process in comparison to traditional methods. The architect models architectural elements before the actual design to facilitate these simulations. . The danger lies in too much progression of the models in this early phase, meaning future models contain less information in the early stages of design. Nevertheless, when the architect releases a model with incomplete information, the process pains the architect because of the inevitable feeling of the model not meeting the standards of the architect.

The completion of the energy simulations requires the presence of the whole design team. Specialist designers and owners agree this process applies to alternative solutions analysis as well. The BIM approach improves the integration of work within the design team, and facilitates more frequent sharing of models in the future. To achieve full benefits, analysis requires also new coordination mechanisms since the design team needs to integrate work in new ways. Cost effectiveness improves by evaluating the degree of difficulty of construction alternatives. However, this analysis typically requires new contractual arrangements to involve expertise about construction.

Analyzing costs based on the building information model proves difficult when the model lacks information needed by the cost estimator. Another challenge occurs as designers publish 2-D drawings before the 3-D models. This process complicates the manner in which the cost estimator receives information and updates. Sharing models of the different designers complicates the process as well. The sharing of incomplete models necessitates a procedure to communicate the unfinished parts. The coordination of a more iterative design process requires new work processes and practices when BIM changes integrated work. In addition, to ensure stakeholders know the data contents to create activities, the model needs to define schedules and milestones.

As a conclusion, the analysis of alternatives for the project in the conceptual design phase represents a major benefit from BIM. The early formulation of the entire design team optimizes the project in terms of construction and life cycle costs. Consequently, the design process shifts ahead. With this in mind, designers need to keep models as light as possible to maintain flexibility in the early stage of the design process.

Supply Chain Integration

Taylor and Bernstein identify supply chain integration as the most advanced BIM practice paradigm. To extend the use of BIM into the supply chain, firms typically need more experience from the use of BIM and working together in the supply chain. The case study data cites the benefits of supply chain integration far less in comparison with the benefits from coordination and analysis. If the argument of Taylor and Bernstein holds true, the emphasis on supply chain integration implies the project network needs more experience in utilizing BIM in opportunities for this area.

The best experiences from supply chain integration derive from the use of models to manufacture foundation reinforcement bars. The model feeds information directly to the supplier systems. Among the suppliers in the industry, steel suppliers appear the most advanced in the utilization of BIM. This data implies steel suppliers already integrate processes. Other industries, such as concrete fabrication, seem to lack behind in the development of systems and procedures to utilize BIM.

Another benefit of supply chain integration stems from the use of BIM to manage logistics. The contractor creates a 4-D presentation based on the 3-D model to schedule the construction of certain elements and deliver the materials and parts to the construction site on time. In addition, the architectural model produces quantities to order windows and doors, for example, from the suppliers.

Facility Management – an Emerging Paradigm

All major benefits in BIM projects fit under the four paradigms Taylor and Bernstein identify. The future of BIM presents great potential in facility management. This potential provides a new, emerging paradigm.

The paradigm of facility management uses BIM during the life cycle of the building. The BIM incorporates the processes of facility management. The as-built BIM poses an example of creating maintenance manuals, virtual observes of facility management tasks, and updates the model after renovations. The best point to start the creation of maintenance manuals occurs during the design phases. This point facilitates the gathering of needed material as the model develops.

The utilization of the building information model during the life cycle of the facility proves important. However, BIM seems to encounter many obstacles to achieve this utilization. Overcoming these obstacles requires the development of processes and systems. Questions remain regarding how facility management uses the model, what information the model needs to contain, and who updates the information during the life cycle of the building.

Based on the case study data, the paradigm of facility management endures in the very early stages. While the benefits of the other four paradigms stand relatively well known, the benefits and objectives related to facility management remain unclear. If facility management truly represents an emerging paradigm as the case study data implies, the AEC industry must develop processes and systems directed towards the use of the building information models during the life cycle of the project.

Process Development and the Business Processes of the Owner

The conceptual framework in the literature review introduces processes on two levels: the project-level and the firm, or company, level. This section discusses the findings relating to the implications of the project-level changes to the business processes of the building owner. The issues divide into three sub-categories. These sub-categories involve the decision points of the owner and represent an integrative approach to project delivery. This approach manages and coordinates the BIM-based design process.

Rethinking the Decision Points of the Owner

Numerous data describe how to evaluate the different alternatives for the project. The alternatives require analysis early in the conceptual design phase to optimize the construction and life cycle costs. Energy simulations allow the owner to analyze different alternatives before the investment decision and allow the design team to examine the energy efficiency of the building, as well as related costs. Based on the analysis, the building structure evolves to meet preset energy consumption targets.

For the owner, such detailed analysis based on a preliminary building element model before the investment decision presents new territory for building projects. Costs and energy efficiency of different alternatives comprise the benefits of this approach. These benefits result from the evaluation of alternatives prior to the investment decision. This approach generates additional costs before the investment decision in comparison to more traditional methods. The use of BIM in such an advanced way forces the owner to consider current business processes. Specifically, the owner must contemplate the timing of such detailed design before the investment decision. Owners also need to determine how to finance the up-front design costs, especially if the investment decision results in a negative return.

Early planning and comparison of alternatives makes sense in unique and complex projects. Simple projects, however, present a scenario in which planning and comparison of alternatives proves feasible. Owner business processes must capture BIM utilization for different types of projects.

Overall, BIM creates possibilities to provide more information to support the investment decisions of the owner. Similarly, analyzing potential problems in the project and thinking of ways to avoid issues decrease the associated risks. However, creating more information requires more design work before the investment decision. The owner needs to decide what kind of projects to provide detailed designs. In addition, owners must compare different alternatives to determine feasibility before the investment decision. Considerable differences lie between new building projects and renovation projects, for example. Owners must account for these differences when making investment decisions.

More Integrative Approach to Project Delivery

Another issue relates to the conceptual design phase and the comparison of different alternatives in this early stage of the project. A preliminary building element model from the architect serves as the basis of the energy simulations. At this point, the involvement of other engineers and the cost estimator proves important to optimize the building as a whole. In addition, knowledge of construction processes substantiates benefits, although the involvement of construction contractors at this stage seems troublesome and premature because of public procurement laws. When utilizing the BIM approach, early involvement of whole design team, including the cost estimator, seems beneficial. Knowledge of construction early in the process also aids the project. The owner needs to consider deployment of these resources without incurring excessive costs.

Stakeholders recognize the benefits of having all parties represented in the early stages of a project. Two different approaches seem evident to employ these resources:

seek bids for the architect, choose the architect, and employ the other professionals as consultants in the early stage of a project, or seek bids for the whole design team at once.

Flexibility and control of specialty designers comprise the advantages of the first approach. Changes to the design team present a disadvantage and causes problems in coordinating future work. The biggest advantage of the second approach occurs when owners commission the design team as a whole, as team members may know one another and work on the project from start to finish. This approach facilitates learning within the design team and decreases conflicts and errors. However, bidding proves more difficult in the second approach, especially for a public owner subject to the federal and state procurement laws.

BIM calls for tighter collaboration and integration of the project participants. The BIM approach encourages the owner to integrate various project members early in the project. BIM utilization influences owner practices to seek bids for projects.

Managing and Coordinating the BIM-based Design Process

BIM brings new types of coordination challenges to the design process. Data acknowledges BIM requires tight integration of the processes of the inter-organizational design team. However, integration tends to misalign the processes of the specialist designers and decrease the benefits from the use of BIM.

Based on the data, an apparent ambivalence exists concerning who should take the coordinator role. Some designers state the role defaults to lead designer. Others feel the project consultant represents the most capable party, and a few stakeholders suggest the use of an external consultant specializing in the coordinator role. Apparently, few people seem to possess the requisite knowledge to manage this highly multidisciplinary role. Markets, ultimately, decide who takes the role as the matter depends on the stakeholder with the most modeling knowledge.

In this state of flux, the owner must reconsider the management practices deployed in projects. GSA and NIST guidelines help to coordinate the use of BIM. The guidelines work in two ways: on one hand, guidelines aid the work of the project managers, and on the other hand, the guidelines help companies understand model requirements. In addition to guidelines, owners must create new contractual agreements to support the use of BIM and ensure stakeholders follow these guidelines.

The creation of the standards facilitates the adoption of BIM in the construction industry. However, to solve coordination problems, projects and BIM require additional attention. Thorough education seems to supplement best real-life project experiences from BIM utilization. BIM influences the construction process in such a significant way project managers require training. Project managers also need to hear experiences and lessons learned from other projects to learn best practices about the new approach.

A Stage-model for BIM Implementation

The conceptual framework illustrates the process of BIM implementation in the project-based construction industry. The framework portrays five stages of BIM implementation visualized in Figure 4.2. The identification of these stages helps companies better understand and manage implementation efforts.

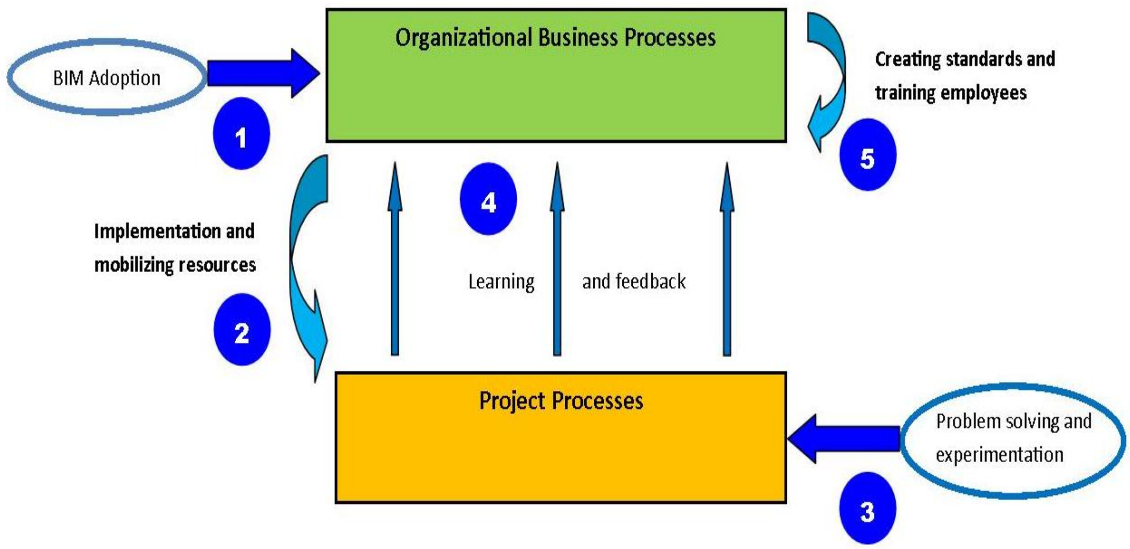

Figure 4.2: Stage-model for BIM implementation

In light of an improved framework, BIM implementation follows a five-staged cycle. First, a company makes the decision to adopt BIM. Several factors influence this decision, including external pressures or the internal interests of the organization. In practice, external pressures mean, for example, a large client requires the use of BIM in a project. GSA remains a strong external change agent for many companies to adopt BIM by demanding BIM deliverables in projects. GSA requires stakeholders, especially the designers and the building contractor, to adopt BIM technologies and practices in order to qualify for projects. Contracts acknowledge these requirements.

Starting the implementation of BIM requires necessary resources, including people and systems. Again, the owner plays an important role in the implementation efforts. Occasionally, for example, owners offer additional resources for companies to more efficiently implement BIM.

The design team develops systems and processes together with project stakeholders to utilize BIM efficiently. Projects provide a fruitful ground for innovating work practices and processes. Companies show this innovation with solutions to technological problems and new ways of working to utilize BIM as efficiently as possible. The findings of this study illustrate how the development of inter-organizational processes contributes to achieving benefits from the use of BIM technologies. The first research question of this study recognizes these process changes and describes the related findings. However, in a project-based business, the efficient utilization of BIM technologies necessitates BIM use in more than one project. The efficient transfer of best practices from projects to the organizations and other projects proves important.

The company network that implements BIM in one construction project takes the lessons learned back to the organizational level, where organizational business processes change based on alterations on the project-level. The second research question of this study identifies the impacts on the business processes of the owner. Lessons learned positively influence forthcoming projects. However, the transfer of the lessons learned presents challenges. To implement the best practices more widely, organizations develop new work standards and train employees. The BIM guidelines that GSA and NIST created to direct the use of BIM represents a good example of this knowledge transformation.

Because of limitations relating to time and resources, a single project achieves only a limited amount of improvements. This limitation generates many future development targets for future projects. For this reason, the five-staged model represents an iterative process. After one cycle, projects create new development targets for the next projects. Manageable, incremental steps achieve this radical development.

The Implementation of BIM in the USA

Industry Foundation Classes (IFCs) and aecXML often associate with BIM. The International Alliance for Interoperability (better known as buildingSMART) continues to develop IFCs. Data structures in aecXML format represent information used in BIM. CAD firms institute other proprietary data structures to incorporate BIM into various software platforms. The AISC (American Institute of Steel Construction)-approved CIS/2 standard, a non-proprietary standard with its roots in the UK, exemplifies one of the earliest examples of a nationally approved BIM standard.

In August 2004, the US National Institute of Standards and Technology (NIST) issued a report entitled "Cost Analysis of Inadequate Interoperability in the U.S. Capital Facilities Industry."[65] The report concludes, as a conservative estimate, the U.S. capital facilities industry loses $15.8 billion annually. These losses result from inadequate interoperability due to "the highly fragmented nature of the industry, the continued paper-based business practices in the industry, a lack of standardization, and inconsistent technology adoption among stakeholders."

GSA promotes the use of BIM and requires models as part of the project deliverables. To aid the use of BIM in its projects, GSA publishes BIM guidelines, which form the basis for projects.

Conclusions

One research question of this study determines the central process changes necessary to realize the benefits of BIM in construction projects. This section describes the benefits from the use of BIM and the process changes to make the efficient utilization

[65] NIST GCR 04-867 (PDF)

of BIM possible. The remaining process challenges identify and explain further development needs to utilize the new technology more efficiently.

BIM Practice Paradigm	Perceived Benefits	Inter-organizational Boundaries Involved	Perceived Inter-organizational Process Changes
Visualization	Communicating designs to project stakeholders	Owner, Architect, End-user, Designers, Contractor, Authorities	Tighter interaction among the project network
	Resolving conflicts between models	Architect, MEP designer, Structural engineer	Processes for visual merging and checking
Coordination	Coordinating work of the design team	Architect, MEP designer, Structural engineer	Synchronizing misaligned work processes of different designers
	Coordinating work on the construction site using models	Structural engineer, Building contractor, MEP designer, MEP contractor	Synchronizing design and construction
Analysis	Analyzing different alternatives and the impact on construction and life cycle costs	Owner, Design team, Cost estimator	Involving participants earlier, shifting design process forward and re-specifying roles
	Checking the realization of requirements for the building	Owner, Design Team, Cost Estimator	Including preset requirements in the design process and testing for realization
Supply Chain Integration	Using the model to produce parts for construction (foundation reinforcement bars)	Structural engineer, Building contractor, Suppliers	Automating/integrating systems and processes between designers and manufacturing industry
	Scheduling logistics to the construction site	Structural engineer, Building contractor, Suppliers	Coordinating processes between construction site and suppliers
Facility Management	No realized benefits yet, but major future potential	Owner, Facility management, Designers, Contractors	Major inter-organizational process and system development needed to utilize BIM in facility management

Table 4.1: Inter-organizational process change to successfully utilize BIM

Table 4.1 illustrates the central inter-organizational process changes to achieve benefits in each BIM practice paradigm. The table shows the main inter-organizational boundaries that involve process changes.

To achieve visualization benefits, project stakeholders increase interaction. Thanks to the illustrative capabilities of BIM, designers communicate better with the end-user, owner, and other authorities. Visual 3-D models allow the design team to resolve conflicts between the different models. To achieve these benefits, new processes for merging and checking models prove essential.

BIM enables the construction project networks to integrate work. At the same time, however, BIM creates new coordination challenges. BIM requires tight integration of the design team, and coordination challenges arise when the designers align design processes to facilitate collaborative work efforts. Harty identifies similar coordination problems in studies of the Heathrow Terminal 5 construction process.[66] In this study, Harty recognizes "the methods hoped to integrate a wide range of skills and practices within one system had the unexpected effect of actually excluding useful and necessary skills from the project." To achieve coordination benefits, the design team needs to develop a highly collaborative design that aligns the sub-processes of specialist designers. On the construction site, contractors use the model to schedule materials and parts for use in construction. However, strict use of the model does not eliminate potential coordination difficulties between the designers and construction contractors. Analysis of alternatives in the conceptual design phase of projects radically improves the result of projects. However, these benefits require several inter-organizational process changes. The design process needs to shift forward. As a benefit, the design team and the cost estimator work together in this early phase. Previously, Hannon reached a similar conclusion.[67] If started early, the design process provides and supports owner decisions. Besides analyzing alternatives in relation to costs, analysis checks the realization of preset requirements. However, work practices must change to acknowledge these requirements.

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[66] Harty, 2005, 520
[67] Hannon, 2007, 5

Within supply chain integration, good experiences gain from steel production. Further benefits from other supplying industries and logistics handling require considerable process development. For facility management, organizations must think about how to use the models during the life cycle of the building. The future needs major process and system development to realize these benefits.

Table 4.1 points out the importance of process development to utilize BIM efficiently. Most of the benefits lend themselves to some kind of development in the project processes. Interestingly, many of these process changes affect multiple firms in the project network, which makes process development a significant challenge. The third column of Table 4.1, “Inter-organizational Boundaries Involved” illustrates the challenges. When suppliers use, the need increases for process changes.

The significant process change needs create difficulties for managing design work in construction, such as deciding when to start modeling, what to model, and who should develop the models. A clear need exists for a person to coordinate and guide the design team from an overall perspective. This person requires the skill set to handle multi-disciplines. The findings of this study imply the role of a virtual project manager proves critical. As a systemic innovation, BIM affects the processes between multiple firms, and someone needs to guide the collaboration of these firms.

The second research question of this study determines how the utilization of BIM and the related process changes affects the business processes of the owner. The case study data shows three distinct areas where process change on the project level significantly influences the business processes of the owner. In the construction industry, Gann & Salter (2000) argue for the need to align the project and business processes. This argument seems to hold true (strikingly similar to the human capital framework). Figure 4.3 summarizes the findings.

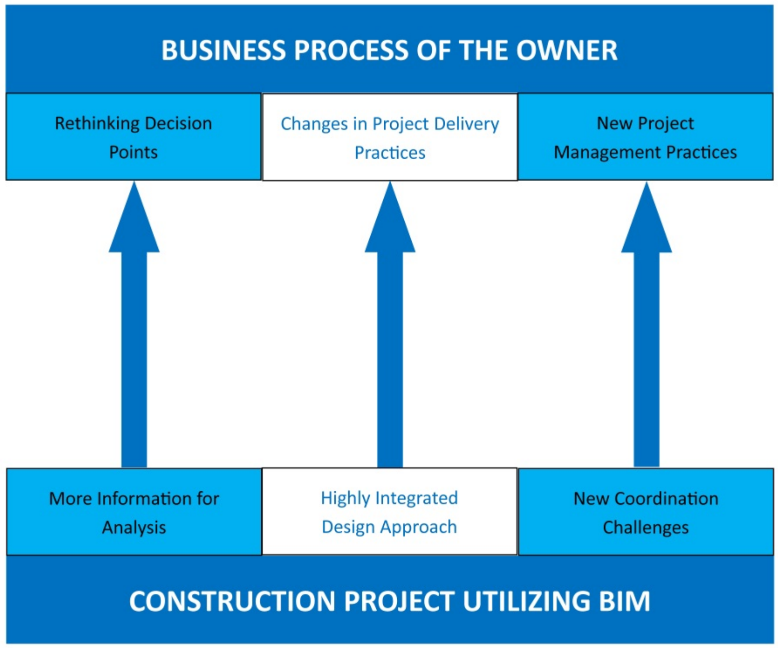

Figure 4.3: The implications of BIM on the business processes of the owner

The building owner needs to consider how design information supports decision making within the business processes of the owner. BIM provides more information, especially in the early stages of a project, which affects the decision making process of the owner.

The findings of this study show BIM encourages tighter integration of the design team and cost estimator. This integration encourages the owner to utilize a new type of project delivery. If the whole design team and the cost estimator are involved early on in the conceptual design phase, the making of analysis to optimize the construction and life cycle costs of the building becomes possible. However, the consideration for life cycle costs creates the need for owners to change bidding practices in current business processes.

While encouraging tighter integration, BIM creates challenges in coordination and training. Someone needs to observe the design and construction companies as a whole to align sub-processes, and the owner needs to ensure such oversight exists. Through the creation of standards, owners represent a powerful party in facilitating the implementation of BIM. The creation of such standards align the business and project processes by translating best practices and experiences from a project to the organizational level and other projects. The creation of new contractual agreements to support the use of BIM in construction projects proves important.

Chapter 5: Conclusions

KEY TAKEAWAYS

This research provides significant conclusions regarding the perceptions and uses of BIM technology. The conclusions lead to a series of recommendations for respective stakeholder groups encompassing how to engage the BIM design workflow, and leverage BIM data to maximize the potentials for affordability and sustainability. Three categories explain the main points of affordability, sustainability, and stakeholder relationships / workflows.

The whole study concludes and highlights the central findings. BIM impacts follow the central findings. The next section discusses the theoretical and managerial implications of the study. Another portion evaluates the research, and the final part suggests future research.

Key recommendations of tis chapter include:

- BIM provides opportunities to support decision-making
- Coordination of team and new project management practices
- BIM impacts affordability (hard and soft costs)
- Impacts sustainability
- Impacts stakeholder collaboration and workflows

Conclusions and Highlights

The objective of this study explores process change needs when organizations implement BIM, a systemic innovation. Using a single case study approach, the research investigates the implementation of BIM. Through a literature review, the research approaches the problem of this study. The literature review concentrates on the following themes: BIM, the implementation of innovation within organizations and construction project networks, the implementation of BIM, and processes and process development. The literature review enables the formation of a conceptual framework. Based on the conceptual framework, two research questions form to answer the broader research problem. The first research question identifies central process change needs for construction projects, and the other question discovers how the changes in the project processes affect business processes. The empirical data consists of project documentation and observations.

The findings of this study show the challenges of BIM implementation because the technology affects the processes of multiple organizations in several phases of a construction project. Achieving the benefits by using BIM requires management of company boundaries. Using a systemic perspective, processes develop by optimizing construction project networks.

The case study shows how achieving benefits through visualization, coordination, analysis, supply chain integration, and facility management require the development of inter-organizational work practices in construction project networks. The needed inter-organizational process changes are diverse and require close collaboration from project network stakeholders. The process changes include synchronization of different work activities, creation of new work tasks, specification of roles between stakeholders, and the definition of data flows to match work in each phase of the project.

Besides integrating companies in new ways, BIM also changes the traditional stages in construction projects. For example, analyzing different alternatives becomes possible earlier in the design process. However, changing the stages of the traditional construction process also creates confusion among project stakeholders. BIM implementation creates pressures to redefine the phases and data contents of the construction process. Clear guidelines direct the utilization of BIM in construction projects. The BIM guidelines of organizations such as GSA and NIST help companies understand the expectations of BIM in projects. Training and the sharing of best practices facilitate efficient utilization of BIM.

The project-based nature of the work characterizes the construction industry, which affects the implementation of new technologies. Previous literature identifies the importance of looking at both the project-level and the firm level when observing innovation and processes in the construction industry.[68] This study discovers the link between the network processes of a construction project and the business processes of the owner when implementing BIM. In this respect, research identifies three distinct implications on the business processes of the owner: rethinking decision points, project delivery and bidding practices, and project management and coordination practices.

BIM provides improved opportunities to bring forth more information to support the decision making of the owner. However, earlier designs generate costs. Before certain decision points, the owner needs to think about the information required. Risks associated with different types of projects vary, and for this reason, these differences require acknowledgement.

Utilizing BIM efficiently requires the tight integration of the project network to the project from the beginning. A specific benefit requires the whole design team and the cost estimator to participate early while contractors provide expertise as necessary. The owner needs to decide how to allocate these resources to the project. Possibly, this means inventing new bidding practices to get participants involved early.

Utilization of BIM involves new kinds of coordination and project management practices. BIM enables integrating the work of the design team tighter than before.

[68] Gann & Salter 2000; Winch 1998

However, this change creates the need to better align the processes of different designers and coordinate the content of the models. Creating standards, such as the BIM guidelines by NIST, helps to manage the utilization of BIM in construction processes. These standards necessitate training to aid project managers.

BIM Impacts on Affordability

In terms of economy and affordability, this study utilizes life-cycle assessments and operational costs. The budget breaks into "hard costs" and "soft costs" (sometimes referred to as *direct* and *indirect* costs respectively). Hard costs encompass procurement for materials, construction, and labor. Soft costs involve administrative costs and overhead associated with the design and/or construction process (for example, permit fees or construction meetings), but do not include financing costs or debt service.

"Hard Costs"

This section discusses various hard costs associated with projects. The research also examines how architects and contractors influence these costs with BIM. The use of BIM technology over more traditional methods, including CAD-based software, may not significantly reduce hard costs. The number and type of projects forms the cause more than the tools to execute the design-construction process. Economies of scale influence the magnitude of savings with respect to hard costs. Not unlike purchasing in bulk, the more projects ready for bid and under simultaneous construction, the greater the savings. Quantity of construction, redundancy, standardization of construction and centralization of resources represent important aspects of this concept. The use of standard detail methods and clear drawing information proves essential to making projects affordable.

An inverse relationship exists between construction complexity and overall cost in the context of current construction practices. As the number of construction types, materials, and details increases, the ability to reduce costs decreases. The strategy to bid the minimal number of sheets and details of a complete set of drawings presents two opposing schools of thought. On one hand, a construction administrator argues the minimization of design information reduces bid costs and project risk because this constraint gives the contractors more freedom to use preferred methods of construction. This thought process leaves much to desire in terms of design intent and quality control. This type of process may create a new "culture of construction" if a strong relationship (common understandings about expectations) exists between the contractor and project manager. Howard Davis explains in *The Culture of Building* increased transparency and learning about tools and procedures in various cultures of construction lead to large-scale improvements to our buildings and cities. Davis argues that having the willingness to break conventional divisions and workflows relies strongly upon stakeholder relationships.[69]

Affordable and sustainable initiatives intend for projects to seamlessly evolve over time and quickly form new stakeholder partnerships while pushing forward innovative strategies. This concept identifies part of a long-term goal to create "a flexible and self-perpetuating delivery system."[70] A part of this vision takes the form of a true design-build process, where the general contractor participates from the very beginning. This process depends on strong relationships between stakeholders. When comparing overall construction methods, design-build project delivery systems project to exceed design-bid-build projects by 20% in 2015.[71] The relationship of the client and architect

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[69] Davis, Howard. The Culture of Building. Oxford University Press, Inc., New York, NY, 2006. 3-5.
[70] The University of Texas Center for Sustainable Development. The Alley Flat Initiative: Topics in Sustainable Development 2008 Report. Austin, Texas: The University of Texas at Austin, 2008. vi.
[71] Elvin, George. Integrated Practice in Architecture: Mastering Design-Build, Fast-Track, and Building Information Modeling. Hoboken, N.J.: John Wiley & Sons, 2007. 22.

represent an import situation. Mark-up costs trend lower when the relationship involves parties that regard the relationship as positive, or possess mutual respect and share similar goals and/or interests. The opposite holds true in negative relationships.

The design development stage (before bids for a project) seems to affect hard costs. An important aspect of this effort, the design team ensures a contractor or builder participates early in the design process. During the early design stages, BIM influences anticipated project costs. The nature of creating a 3-D parametric model that supports bi-directional references creates a "what you see is what you get" type of environment. BIM models often include renderings and 3-D images in the drawing set to communicate design intent to stakeholders. The design team addresses any issues or concerns during the early stages of design because the BIM model shows accurate information. This important step encourages builder buy-in early in the design process for accurate cost estimates. Many BIM software tools, including Autodesk Revit Architecture, perform material quantity takeoffs directly from the parametric model. This data provides a quick and accurate means for estimating hard costs.

Revit Architecture supports the BIM model and quickly extracts material quantities based on the model parameters. As changes occur in the model, the quantity values update in real-time. To provide cost estimates, designers enter costs per material quantity into the Revit database. Autodesk AEC Education Solutions state Autodesk Quantity Takeoff provides better cost estimates in comparison to performing the function inside Revit Architecture.[72] This process exemplifies how certain workflows intentionally develop for collaboration between various AEC companies. This example speaks to the fact BIM benefits large-scale, large-budget projects. Because of

[72] AEC Education Solutions Specialist, Autodesk Inc.

development and marketing efforts, this technology does not afford the same benefits to small-scale, small-budget projects.

The combination of incorporating a contractor early in the project design phase and utilizing BIM for quick and accurate cost estimates, leads to the conclusion effects to hard costs in any significant fashion depends on social and technological practices. From a social perspective, appropriate stakeholders need to coordinate contractor or builder involvement in the design process. Risk management presents a key component to cost control. Informal collaboration requires good faith and trust between groups. The nature of the project determines the phenomenon of informal versus formal relationships. Typically, small-scale, small-budget projects, for example, narrow the number of potential players.

From a technological perspective, BIM represents a very useful tool because of the capabilities to extract material quantities and calculate cost estimates quickly and accurately from the digital model. CAD-based design and documentation tools require manual tabulation and add time to achieve similar results. Although most BIM tools handle material and quantity takeoffs, design teams must purposely utilize the capabilities in this fashion. Few contractors and designers use BIM to coordinate construction costs across trades. Therefore, the use of BIM to coordinate construction costs among the design team represents a real opportunity for affordable and sustainable projects. The opportunity requires stakeholder collaboration and competent use of BIM technology.

In summary, the implementation of BIM as the sole purpose to replace CAD seems to result in insignificant reductions to hard costs. The key to address hard costs uses the technology in following ways: use BIM as a communication tool to visualize the design / construction intent clearly and use BIM as a quantifying tool to minimize contractor guesswork.

“Soft Costs”

This section reviews the soft costs associated with projects. There are two types of indirect costs: *explicit* and *implicit*. BIM technology affects both costs; however, the implicit costs represent the greatest long-term expense.

Soft costs include administrative expenses, overhead, fees, and other indirect costs for building development (not including financial costs or debt service). The majority of these soft costs trace to local governments. These governments dictate the manner developments occur and the process to ensure compliance with applicable codes and ordinances. Because of the current economic downturn, fees continue to increase dramatically, which in turn adds financial burden to affordable/sustainable projects. Although this solution appears to mitigate soft cost expenses, the solution fails to address the root of the costs or the tools to facilitate information workflows between stakeholder groups. The information workflows represent the probable cause for the inflated fees. Furthermore, not all governments develop incentives to offset the administrative fees associated with development.

Encouraging the use of BIM as an integral part of the review process represents an important step in addressing inefficiencies and saves money in the end. Once stakeholders realize BIM serves as a production tool and means to communicate, the perception all the tools used to communicate design intent are equal fades and changes. When the design team clearly communicates the design intent for projects, the review process realizes savings in time, which in turn, reduces the number of staff hours and overall cost to review projects. Currently, affordable projects average a four months review, start to finish. The consequence of such delays increase economic risk and inflate soft costs.

Wisconsin and Texas comprise the only state governments that require BIM utilization for commissioned projects (note, GSA started the requirement of BIM models for federal projects since 2007).[73] However, unlike Wisconsin, Texas requires all projects use a single BIM platform – Autodesk's Revit. The BIM information proves valuable for design and construction, and tracks changes over time. The ultimate goal creates an "enterprise solution" which allows real-time collaboration and links this information to an online "Google Earth" type interface. The collaboration prompts for building data through visual means and requires appropriate access rights. The ambitious path some government agencies take to implement BIM shows great potential. However, several barriers prevent a smooth transition currently. The use of BIM depends less on project type and more on the number of stakeholders and the complexity of the relationships between the stakeholders.

The appropriate BIM software requires a substantial financial investment and necessitates the overhaul of current review processes. Research by various government agencies reveals the investment cost for implementing a BIM process ultimately pays off. BIM presents many possible uses: a code compliance tool (visualization for design intent); central clearinghouse of project information to update and future use as data comparison; and BIM saves staff time and reduces review errors.

Soft costs include the investment required for BIM software and long-term training. In addition, soft costs include supplemental costs due to current inefficient practices. The contributions of these indirect costs prove difficult to track. NIST found in a 2002 study workflow inefficiencies account for an average increase in construction costs by $6.35 per square foot for new building design, construction, operations and

[73] www.buildinggreen.com/auth/article.cfm/2009/10/30/States-Adopt

maintenance.[74] In case study examples, BIM demonstrates reductions in both time and costs associated with the inefficient use of technologies in the AEC industry. According to the NIST estimate, a building of 1,000 square feet expects an increased cost of $6,350 due to interoperability inefficiency, assuming stakeholders utilize conventional tools and methods. Communication errors occur for the opposite reason - stakeholders utilize inappropriate technology to communicate with each other. BIM mitigates these indirect soft costs; however, BIM demands a balance between the upfront investment of BIM software and training costs.

BIM Impacts on Sustainability

With proclamations as a new and more efficient process for design and documentation, BIM also heralds "the ability to help guide the industry in a more sustainable direction by allowing easier access to the tools necessary to quantify a greener design approach."[75] Eddy Krygiel and Bradley Nies outline various strategies for the performance of "green" design with BIM tools. Both argue although not new strategies, the tools evolve and achieve "green" design goals much easier. Some "green" design strategies present barriers when designers attempt to use Revit. Several "green: strategies take substantial effort and time and do not always work. Limited expertise with BIM software may lead to unintended results.

Although BIM intends to save time and effort, the intention proves in the reverse should users lack experience or if designers use the software for unintended purposes. Many BIM tools feature plug-ins specifically oriented to early design analysis.

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[74] Eastman, Charles M., et al. BIM Handbook, 11.
[75] Krygiel, Eddy and Bradley Nies, 25.

On rare occasions, a single BIM tool delivers useful analysis for “green” designs. However, many times, “green” design strategies require multiple software packages to derive meaningful results. Thermal load analysis represents a good example of the need for multiple software platforms. Thermal gain/loss calculations present functions beyond Autodesk Revit Architecture capabilities. The BIM model from Revit, however, exports as a gbXML (Green Building XML web-based format) to an energy analysis program, such as Autodesk Ecotect Analysis. In an ideal world, software tools for design and analysis present an “all-in-one” solution. This software proves inexpensive to purchase and easy to learn. Unfortunately, prohibitive costs and difficult learning curves limit the usefulness of reality, software packages – no matter how robust and capable.

BIM tools make “green” design easier, although not the only prerequisite to achieve sustainable design. Social and political agents support the use of BIM to meet sustainable design goals. The social aspect encompasses the various stakeholders with affordable and/or sustainable development and the common goals for these kinds of projects. For example, owners outline design expectations for projects, such as minimum R-values, HVAC systems, passive design strategies, efficient appliances and plumbing fixtures.

Coupled with energy savings incentives, a BIM model quickly produces the information needed to ensure implementation of “green” design strategies. For example, rebates for rainwater harvesting require an application that includes calculations for the total area of water collection and the total area of irrigated landscape. The BIM model derives these areas and adds the values to a schedule with formulas to calculate the required information for the application. Another example involves using the BIM model as a code compliance mechanism. In this case, specific views of the model demonstrate compliance. Furthermore, the government agencies could pursue a more standardized visual review method that leverages the power of BIM technology. In an integrated design process, BIM and sustainability represent important facets of the design process.

BIM Impacts on Stakeholder Collaboration and Workflows

This section examines how BIM improves stakeholder relationships and information workflows throughout the design and construction process. The following discuss two major conclusions: collaboration early in the design process, and new relationships solidify faster with the use of BIM; and the information database evolves from the BIM model to integrate "expert" and "non-expert" knowledge.

Similar to addressing issues of cost and 'green' design; collaboration also relies on both social and technological means. From a social perspective, BIM encourages an integrated design and construction process, which depends on early collaboration between stakeholders and members of the design team. Integrated Project Delivery (IPD) commonly refers to this process. Through the utilization of BIM tools, an IPD approach integrates participants, building systems, and business practices into a process. This process benefits from the knowledge of everyone involved to optimize the intended results of the project.[76] The benefit stands in contrast to conventional building industry practices where each group operates in disjointed and fragmented relationships – coordination typically only occurs to address a problem. A BIM process, however, demands early input from building trades as limits to design information in a parametric model and linked database proves difficult.

Incompatible software presents a primary obstacle to IPD. Technological impacts on collaboration exemplify such an example. Compatibility between stakeholders requires various software platforms exchange necessary information and data via

[76] AIA and AIA California Council, 2007.

common file formats. In response to this obstacle, the adoption of Industry Foundation Classes (IFC) represents one potential solution. Developed in the mid-1990s as a product data model, this nonproprietary open source standard began allows for compatibility between AEC software tools for the full lifecycle of a project.[77] For example, if IFC compatible, software imports/exports relevant information from a BIM digital file and represents the data for a particular use, such as architecture, construction or engineering. The benefits of IFC seem far from full realization since major proprietary BIM software developers limit adoption. In the case of Autodesk, the company feels the development of a common exchange file format represents a waste of time and money to invest (especially when the company already maintains a controlling share of the building industry market). The demand for compatibility, interoperability, and standardization moves the building industry forward, whether or not proprietary software developers dominate the BIM market or common exchange formats become commonplace.

The issues of compatibility and interoperability with BIM are not necessarily equal for all AEC groups. Much of the attention on BIM orients towards larger companies. In the case of affordable and sustainable development, however, the audience usually represents small-scale and generally less high technology companies. Therefore, the introduction of BIM in this context represents a different challenge. Instead of a concentration on information exchange between BIM platforms, the goal grows to the extraction of BIM information for low-capacity software. Low capacity means any software less capable of managing and associating building design information. Examples of low-capacity software include programs such as Microsoft Excel, Word, and Adobe Acrobat. Stakeholders commonly use these file formats to

[77] Eastman, Charles M., et al. BIM Handbook, 67-84.

exchange information. In addition, most communication occurs via emails, phone calls, or in-person meetings.

Jerry Laiserin, a consultant for AEC/O businesses and one of the fathers of the BIM movement, argues that although a powerful tool for documentation and design, the justification of BIM use does not apply to all projects. He explains this idea with two categories: *building-centric* and *client-centric*. The building-centric reason relates to the size, complexity, and flexibility of the project. He uses the typical strip-mall as an example of a standard, uniform and minimal design building type for which BIM affords no benefit. While BIM provides some "design" value, a greater benefit derives from substantial improvements to strip-mall development patterns. Urban planning and building codes better address these development patterns. The client-centric category deals with the type and capacity of the building client. Laiserin states a significant proportion of clients lack the management capacity and software technology to benefit from complex data-rich models produced by BIM technology.[78]

Laiserin fails to acknowledge some key points, however. Design and/or documentation need not limit BIM. BIM use includes code compliance and energy performance. The BIM model provides information for the entire life cycle of the project and manages data for many projects within an urban environment. A single project, by itself, may not prove complex; however, a network of projects connected to urban infrastructure proves entirely different.

The client-centric perspective also represents some misunderstood complexity. Whereas most small-scale projects involve a single client stakeholder interest, not all

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[78] The Laiserin Letter. "Designer's BIM: Vectorworks Architect keeps design at the center of BIM process." Jerry Laiserin. 15 March 2010. <http://www.laiserin.com/features/issue26/feature01.pdf> (March 2010).

small-scale projects function in this manner. Local governments use BIM as a management tool and provide template/training services to qualifying developers. Social and political complexities prove unique between stakeholder relationships and justify the use of BIM, regardless of typological criteria.

The AEC industry requires a hybrid approach in general. Designers should not expect to use the same type or extent of BIM collaboration in small-scale projects in comparison with larger AEC firms on complex projects. A hybrid approach appears likely. In other words, a majority of architects and contractors use BIM technology in the near future with the understanding the future changes how this technology functions and current methods of marketing. At present, BIM tools appeal to specific professions in the building industry to address workflow requirements within each group. While adequate in addressing current building processes, the process intentionally or unintentionally ignores stakeholder relationships and the communication between stakeholders – especially those outside the AEC industry. A lack of common understanding and accessible interfaces represent an apparent issue when extending the application of BIM beyond the building professions.

Smith & Tardif explain that every stakeholder in the building life cycle needs to view building information from his or her own perspective. This need means each stakeholder represents an interface requirement. Since so few information interfaces exist, this requirement serves as one of the most challenging obstacles to sharing building information.[79] Communication of data represents the challenge in lieu of expectations for everyone to understand how to use BIM tools. BIM leverages data through a relatable user interface to each stakeholder group. Current Autodesk experiments involve the

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[79] Smith, Dana K., and Michael Tardif, 146.

development of a web-based social networking interface to communicate between software tools and people on projects. Clearly, the company recognizes the demand for the inclusion of a variety of stakeholders, although the current technology utilizes a uniform interface for all groups. The next step customizes each interface based on stakeholder needs. A step beyond the customization of interfaces (probably beyond the reach of any particular BIM software vendor) addresses the language of communication with relation to project development. While a good deal of common language exists between AEC groups, identical terminologies and language within the building industry does not necessarily translate when outside stakeholders interpret the information (such as financial institutions, governments, local residents and non-profit organizations).

Dammann and Elle (2006) investigate the potential of establishing a common language for "green" design. The research analyzes the context of the Danish building sector.[80] For example, the term "sustainable design" means one thing to an architect and something completely different to a local resident in the community. Historically, the translation of the meaning of these important terms represents the challenge to mitigate miscommunication and improvements to group relationships. The authors identify four "technological frames"[81] which correlate to four different understandings, goals, and perspectives of "green" design:

1. Public-relations Frame
2. Scientific Frame
3. Aesthetic-holistic Frame
4. Lay-person Sensualist Frame

[80] Dammann, Sven and Moren Elle, 387-404.
[81] W.E. Bijker, 1995

Areas of consensus and conflict exist. Based on the evidence, the authors conclude the idea of creating a common indicator language to ensure consensus between groups appears unlikely in the near future. Dammann and Elle propose three likely scenarios to transpire in the future. One scenario in particular, titled "Science goes public," presents a tandem pursuit with future BIM development. For example, if an owner mandates the use of BIM include the development of templates specific user templates contain this multi-tiered language. Alternatively, a possible scenario takes the form of visual communication methods. In this case, BIM evolves into an asset for communicating information through visualization means. The same model information for design and construction expands to provide a communication medium devoid of confusing jargon. This method applies to design-specific items on a limited basis since the method proves inappropriate for all communication intents.

In summary, the use of BIM allows for improvement opportunities in the areas of affordability, sustainability, and stakeholder relationships/workflows. To view the BIM process and software technology with broader uses and implications than current uses, the key ensures success in these areas. Stakeholders need to view and utilize BIM as an integral part of design (codification, documentation, energy analysis, fabrication, quantification and renderings), communication and social networking. Recommendations intend to foster a new kind of discourse regarding current uses of BIM. In addition, recommendations demonstrate how this technology improves future affordable and sustainable development.

Theoretical Implications

This study concentrates on new knowledge to the issue of process development while implementing BIM in the project-based construction industry. The findings support previous theories that emphasize the relationship between IT and processes.[82] As Davenport and Grover, et al. offer, IT represents a powerful enabler for process development. However, to exploit these opportunities, process development must proceed beyond the automation of existing processes. This case study shows how the successful implementation of BIM requires changing the traditional phases of construction process as well as the interrelationships between the project network companies.

This thesis complements previous studies on BIM implementation by combining achieved benefits with the process changes needed to utilize BIM efficiently. The findings reinforce the results of Harty (2005) and Taylor (2007), which identify the need for a systematic perspective when implementing technologies that cross organization boundaries. This study acknowledges how BIM implementation requires process changes spanning several boundaries within the construction project network. This study also proposes a new multidisciplinary role to align the inter-organizational processes of construction companies. However, current project network members fill this role, as well as other stakeholders depending on current capabilities. This study also adds to the Taylor and Bernstein model on BIM practice paradigms and recognizes a new emerging paradigm, facility management. The use of BIM in facility management represents one likely and important development area of the future.

In addition to the project-level findings, this study clarifies the link between project and business-level processes in the project-based construction industry. Gann and Salter (2000) identify coherence between the processes on these two levels. However, the combination of this model with the construction innovation process/model by Winch

[82] Davenport 1993; Grover et al. 1998

(1998) illustrates how the implementation of new technologies on projects may have significant implications on organizational business processes. This study shows how the process changes in the project-level force the owner to rethink project delivery, bidding practices, information needed for central decisions, and project management practices.

Managerial Implications and Recommendations

The managerial implications of this study relate to three different levels of analysis: the construction project-level, the level of owner, and the implementation of BIM in the industry in general. This study helps firms better understand the implementation of BIM from a process perspective. The model for BIM implementation in the project-based construction industry helps companies view the implementation of BIM in a new perspective and finds ways to tackle encountered problems.

This study emphasizes the need for construction companies to develop processes beyond organizational boundaries when implementing BIM. Development must occur within construction projects as stakeholders experiment with new processes, and recognize and solve challenges. Construction projects require a virtual project manager to coordinate the work of multiple specialists and optimize inter-organizational processes. This role proves important during the implementation of BIM and different stakeholders develop and accept new work practices. Owners must ensure this position exists in the BIM projects of today.

The BIM guidelines of GSA provide a good basis for project management, which makes the use of BIM mandatory. However, this study influences the project-level, and BIM affects the business processes of the owner. In addition to developing the processes of the project, owners must consider the practiced business processes to match with BIM through project delivery. During this research, a way to illustrate this action combines the investment process with a construction process through acknowledgment of BIM guidelines to understand the linkages.

This case study also reveals coordination of the building process utilizing BIM differs from the traditional process in such significant ways that project managers require considerable training to define in the beginning of the project what to model and the overall project delivery. In addition to training, managers incorporate systems to share experiences among different project managers to identify best practices for use in certain types of projects. This practice accelerates the efficient utilization of BIM within projects. If owners gather experiences from multiple projects, the BIM guidelines further develop. This development moves toward a new type of building process that efficiently utilizes BIM technologies.

Evaluation of the Research

Typically, the criteria of internal validity, external validity, reliability, and objectivity judge the rigor of inquiries. Internal validity refers to the truth-value of a given inquiry, meaning the extent to which the inquiry establishes what things represent and how these things really work. External validity concerns the generalization of the findings, which states how findings apply in other contexts. Reliability responds to questions about the consistency of a given inquiry, which means that replication of equivalent instruments lead to similar measurements. Objectivity refers to neutrality, which means the study contains vale without bias and prejudice.[83]

To analyze the internal validity, external validity, reliability, and objectivity of qualitative research, Lincoln and Guba (1985, 300) propose the criteria of credibility

[83] Guba & Lincoln, 233-235

(parallel to internal validity), transferability (parallel to external validity), dependability (parallel to reliability), and conformability (parallel to objectivity).

The transfer of research describes the context of completed research and defines the completion of the study. In this way, others apply the research to individual situations.[84] In a case study, several factors present unique facets to the case in question. When evaluating the transfer of findings, take the context of the research into account.

For example, Taylor and Levitt (2007) found that different project structures and work practices significantly implicates the diffusion of BIM technologies. Since the project had a public owner, the delivery model of the project might differ from private companies. Because of differences between public and private organizations, the implications of BIM on business process differ between public and private owners. Results considering bidding practices might be highly different. Applicable to both public and private owners, the findings relate to the new coordination challenges. The experience level of the participated companies in the use of BIM may have significant implications on the results. Completion of the same study with another project network could lead to different results because of the varying experience levels of the project companies.

Taylor and Bernstein (2008) identify paradigms to consider when evaluating the results. The four paradigms - visualization, coordination, analysis, and supply chain integration - describe the benefits BIM offers. Dividing the data according to these paradigms enables observation of what kinds of process changes achieve these benefits. However, besides the implemented process changes, this study analyzes process problems to achieve better results. In addition, the findings relating to the second

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[84] Guba and Lincoln, 241-242

research question enable the avoidance of restrictive analysis by the paradigms. Note this study concentrates more on early planning and design phases, and the boundary between design and construction than actual construction of the project or managing the supply chain.

The specific project heavily influences the framework and the included process of BIM implementation. The owner, ultimately, facilitates the implementation of BIM, although a powerful player may not always exist. Based on the findings, BIM significantly affects the business process of the building owner; private owners may not share similar effects. Moreover, BIM may affect the business processes of other organizations involved in construction projects. This study discusses the challenge of transferring knowledge from one project to another project.

RECOMMENDATIONS

The Appendix contains tables for typical stakeholder groups involved with AEC projects. Recommendations outline how each stakeholder interaction leverages the power of BIM to reduce costs, increase efficiency, improve sustainable design, and develop better information workflows. This section also includes various incentive strategies as a means to offset the challenges associated with implementing BIM as a technology and process. Some areas of overlap exist between stakeholder roles and opportunities, since a single approach for every situation seems impractical. The recommendations require each stakeholder to engage BIM in the suggested fashion.

Future Research

Publically available information limits the research and does not garner insight into the actual culture and structures of the organizations that have implemented BIM. This thesis emphasizes BIM implementation in the face of adopting technologies that present a disruption to current practices and processes. The intent of this research continues to develop and evolve as technological changes occur with regard to BIM. The findings of this study raise several future research questions to address in the context of the implementation of BIM. A related and promising continuance of this research topic explores the benefits of BIM versus CAD workflows for multiple projects. BIM reduces soft costs through a decrease in the time necessary to complete construction documents and make revisions. Overall, this research requires testing BIM and non-BIM workflow strategies for various ventures over entire project timelines.

A second area of research combines or links information between BIM and GIS. Most cities and counties in the US maintain GIS data, which typically include building footprints, demographics, land-use, plots, streets, topography, utilities, vegetation, and zoning. This information proves valuable for gathering statistics and development planning. BIM provides value to gathering specific information about building components and local site information. GIS exemplifies a macro-information tool, and BIM, by comparison, characterizes a micro-information tool. However, each tool tends to reference information represented in the other. Recent interest centers upon how BIM and GIS databases link and share data between platforms. The potential benefits of merging information databases present enormous long-term benefits for city planners and developers.

A third topic involves closer examination of the economic aspects of using a BIM process to facilitate communication between stakeholders. The use of an alternative incentive structure oriented around BIM could significantly influence soft costs, especially for governments, which typically incur the greatest overhead costs. In addition, the cost savings offset the initial software purchases and continual training costs associated with higher-capacity BIM tools. The states of Texas and Wisconsin require state buildings use a BIM process; however, this regulation mandates no other building types. This research requires the orchestration and testing of partnerships between BIM software developers, governments, utilities, local architects/contractors, and clients/owners. To identify the potential uses for the models during the life cycle of a facility, companies could develop the processes and systems to realize the BIM benefits for facility management. Some of the issues to address include the kind of information required to utilize the models; the process to transfer information to facility management systems; and how real estate managers use this information in daily tasks. Further research should study if the process development challenges relating to BIM compare in disintegrated and integrated projects. Additional study may determine how project type (for example unique versus simpler project) influences process development needs.

Future research investigates if new businesses or business models arise because of the implementation of BIM. A promising research theme involves how organizations in a project-based business efficiently transfer information, knowledge, and experiences from one project to the organization and other projects. When implementing innovations in the project-based construction industry, information transfer proves important because development of the capabilities to convey experiences and knowledge accelerates the adaptation of innovations.

The above topics do not intend to represent an exhaustive list. The subjects offer suggested topic outlines to benefit from this research and expand into other areas of benefit to BIM and affordable/sustainable development in the future.

Appendix

	Architects and Designers
Owners and Developers	• Use BIM to present design options accurately, efficiently and quickly • Present design options to owners and developers • Leverage BIM model data to link directly with spreadsheets and text documents – quick access and updates by owners and developers
Architects and Designers	Role: Use BIM to: 1. Increase design workflow efficiency 2. Coordinate qualitative information with stakeholders
Builders and Contractors	• Use BIM to export and link quantity takeoffs and fabrication datasets for bids and construction
Green Industries	• Coordinate with "green" industries to integrate smart modeling components with BIM software tools • Negotiate with "green" industries and BIM developers to create innovative components • Develop innovative components for affordable and sustainable projects
BIM Developers	• Negotiate with BIM developers and distributors to license software at discounted rates • Specifically target affordable and sustainable projects • Discuss pricing models for affordable and sustainable project teams ("rent as you go?") • Provide feedback to BIM developers for project and stakeholder needs • Assist in creation of development of linkages to spreadsheets (for example, Excel) directly from the parametric

	BIM Developers
Owners and Developers	• Convince owners and developers of financial paybacks and savings, or ROI, associated with using BIM tools for project development and communication with stakeholders • Market BIM tools specifically for affordable and sustainable projects • Make value-based arguments for BIM implementation • Use BIM tools to calculate life cycle costs
Architects and Designers	• Provide affordable BIM software financing options • Provide specific financing for small and sole operated architects and designers involved with affordable and sustainable projects • Consider a "pay as you go" price model • Provide project support through troubleshooting modeling problems • Help users achieve design solutions
Builders and Contractors	• Market BIM tools specifically for small-scale builders and contractors involved with affordable and sustainable projects • Continually develop interoperability between "high-capacity" BIM tools and "low-capacity" information software (such as Revit and Word, respectively)
Green Industries	• Consult with "green" industries to leverage BIM capabilities. Demonstrate "green" initiatives and design strategies. Negotiate "green" materials, systems and technology. Promote donations for affordable and sustainable projects that incorporate BIM models for future use.
BIM Developers	Role: • Develop BIM tools specifically to meet the needs of affordable and sustainable projects • Develop BIM tools specifically for project stakeholders • Provide affordable price models for software purchase and training workshops

	Builders and Contractors
Owners and Developers	• Use BIM to provide project cost estimates during bid phase for owners and developers • Coordinate with architects and designers to export BIM model quantity takeoffs for accurate cost estimates • Use interoperable tools to track quantities and costs (as-builts)
Architects and Designers	• Work closely with architects and designers to standardize project specifications using BIM tools • Suggest specification format and information requirements to link or embed in BIM tools • Communicate required information for building systems to maximize efficiency through standardized formats • Link specification information to the BIM model
Builders and Contractors	Role: 1. Use BIM to increase efficiency and accuracy for bidding, cost estimates, material quantities, and phasing 2. Incorporate local building knowledge into BIM tools to communicate preferred construction techniques
Green Industries	• Collaborate with "green" industries to incorporate innovative building systems and technologies into BIM tools • Request specifications or cut sheets from manufacturer and provide data to architects and designers – include preferred installation and construction methods • Provide preferred construction and installation methods to develop parametric models for use with BIM tools
BIM Developers	• Request BIM developers integrate local construction practices into BIM modeling parameters and/or online components for download • Create component or parameter options • Request BIM developers create interoperable file formats between "high-capacity" BIM tools and "low-capacity" information management tools commonly used (such as Revit and Excel, respectively)

	Green Industries
Owners and Developers	• Work with owners and developers to determine ROIs for using "green" building strategies • Leverage BIM to quantify cost and material data to compare with upfront investment costs
Architects and Designers	• Provide associated BIM content and parametric modeling data for "green" building components • Incorporate "green" building components into design processes of architects and designers
Builders and Contractors	• Work with builders and contractors to leverage BIM modeling capabilities to visualize construction methods for a specific "green" building element • Clear communication of construction and installation techniques by using parametric modeling interface reduces ambiguity and errors
Green Industries	Role: • Use BIM to incorporate innovative and sustainable design materials, systems and technologies • Specify sustainable design. Materials and systems for affordable and sustainable projects
BIM Developers	• Request BIM developers train "green" industry staff to develop parametric BIM components • Provide parametric components to download for use in affordable and sustainable projects • Request BIM developers take development responsibility in exchange for making "green" components available for public use

	Owners and Developers
Owners and Developers	Role: 1. Use BIM as a communication, cost estimating, marketing, presentation and tracking tool 2. Manage project data for archives and future development of project
Architects and Designers	• Negotiate contracts based on the use of BIM tools and information workflows • Work closely with architects and designers to leverage BIM for communicating information regarding accessibility, energy analysis, project context, project phasing, and programming • Stress analysis of project life cycle costs and effects of these costs on large and small scale projects • Analyze ROI based on specific affordable and/or sustainable design strategies
Builders and Contractors	• Leverage BIM to collaborate on projects • Use an online, real-time digital interface to review construction progress and condition of as-builts • Link spreadsheet data and other formats for cost control and phasing with BIM models and tools
Green Industries	• Consult with "green" industries to leverage BIM capabilities • Demonstrate "green" initiatives and design strategies • Negotiate "green" materials, systems and technology • Promote donations for affordable and sustainable projects that incorporate BIM models for future use
BIM Developers	• Negotiate with BIM developers and distributors to license software at discounted rates • Specifically target affordable and sustainable projects • Determine appropriate contract structures for specific BIM technologies

Acronyms

2-D	Two Dimensional
3-D	Three Dimensional
4-D	Four Dimensional (Time)
5-D	Five Dimensional (Cost)
ADSK	Autodesk exchange file
AEC	Architectural-Engineering-Construction
AGC	Associated General Contractors
AIA	American Institute of Architecture
ARCHiPHISIK	software to analyze energy efficiency within building design
BIM	Building Information Modeling
BMP	Bitmap file format
CAD	Computer Aided Design
DGN	MicroStation design file
DOE-2	Widely accepted freeware for building energy analysis developed by US Department of Energy
DWF	Design Web Format file extension
DWG	Autodesk drawing file extension
DXF	Direct eXchange Format
DXF	Drawing Interchange Format
FAIA	Fellow, American Institute of Architecture
FBX	File format for interoperability between digital content applications
FCI	Facility Condition Index
gbXML	"Green Building" XML
GIS	Graphic Information System
GSA	General Services Administration
HTML	HyperText Markup Language
IAI	International Alliance for Interoperability
IFC	Industry Foundation Class
IGES	Initial Graphics Exchange Specification
IPD	Integrated Project Delivery
JPEG	Joint Photographic Experts Group file format
JPG	Alias for JPEG
LCD	Liquid Crystal Display
LEED	Leadership in Energy and Environmental Design
MEP	Mechanical, Electrical, Plumbing
MP3	Alias for Moving Picture Experts Group-1 or MPEG-2 Layer III file format
NBIMS	National BIM Standards
NIBS	National Institute of Building Sciences

NIST	National Institute of Standards and Technology
OCA	Office of Chief Architect
ODBC	Open Database Connectivity
PBS	Public Buildings Service
PDF	Portable Document Format
PNG	Portable Network Graphics file format
RIUSKA	IFC file format for use in energy analysis software
ROI	Return On Investment
RVT	Revit file format
SAT	Standard ACIS Text format
SKP	Sketchup file format
STEP	Standard for the Exchange of Product model data format
STL	Standard Tessellation Language
TIF	Tagged Image Format
USACE	US Army Corps of Engineers
XML	eXtensible Markup Language

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Vita

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